

RANGE

BEEF COW SYMPOSIUM XXIX

November 10-11, 2025

Event Center at Archer, Cheyenne, Wyoming

PROCEEDINGS



HOSTED BY UNIVERSITY OF WYOMING

www.rangebeefcowsymposium.com

29TH BIENNIAL RANGE BEEF COW SYMPOSIUM

November 10-11, 2025

Event Center at Archer, Cheyenne, Wyoming

PROCEEDINGS

Table of Contents

(Alphabetical by First Author)

Global Trade In The Beef Industry	3
<i>Tyler Cozzens, Colorado State University</i>	
Co-Producing Range Beef Cow Research With Ranchers: Lessons Learned And Future Opportunities	6
<i>Justin D. Derner, USDA-Agricultural Research Service; Mark Eisele, Kendall Eisele, Kaycee Eisele, King Ranch</i>	
Cost Of Production In The Cow-Calf Sector	15
<i>Brandon Dodd, Colorado State University</i>	
Influence Of Nutritional Management On Bull Fertility	19
<i>Pedro L. P. Fontes, University of Georgia; Lucas Melo-Gonçalves, University of Georgia; Saulo M. Zoca, University of Tennessee</i>	
Leveraging Reproductive Technologies.	29
<i>Kacie L. McCarthy, University of Nebraska – Lincoln; Shelby L. Rosasco, University of Wyoming</i>	
Carbon Credit Markets	39
<i>Nicole (Nicki) Nimlos, University of Wyoming</i>	
Impacts Of Late Gestational Undernutrition In Beef Heifers On Dam And Offspring Outcomes.	45
<i>Colby A. Redifer, University of Missouri; Allison M. Meyer, University of Missouri</i>	
Genomic Testing In The Commercial Herd	50
<i>Troy N. Rowan, University of Tennessee</i>	
Impact Of Ranch Decisions On Calf Value In The Feedyard	57
<i>Warren Rusche, South Dakota State University</i>	
Pulmonary Hypertension: New Research And Developments	66
<i>Scott E. Speidel, Colorado State University; R. Mark Enns, Colorado State University</i>	
Pulmonary Hypertension: New Research And Developments	72
<i>Chase D. Markel, University of Wyoming</i>	
Using Virtual Fence To Improve Grazing Management On Rangelands	76
<i>Mitchell Stephenson, University of Nebraska – Lincoln; Yijie Xiong, University of Nebraska – Lincoln; Mary Drownoski, University of Nebraska – Lincoln; Elliot Dennis, University of Nebraska – Lincoln; Hanifi Otgun, University of Nebraska – Lincoln</i>	

GLOBAL TRADE IN THE BEEF INDUSTRY

Tyler Cozzens
Livestock Marketing Information Center
Colorado State University

INTRODUCTION

When one visualizes global trade in the beef industry, one may be tempted to think of trade as simply exchanging cattle between buyers and sellers. However, the dynamics underpinning those exchanges are complicated and fluid. This paper considers some of those factors as it provides a snapshot of the fed beef / export market, nonfed beef / import market, and live cattle trade as they relate to the U.S. and its trading partners.

FED BEEF / EXPORT MARKET

The export market in the U.S. can be defined by the sale of high-quality beef products derived from grain finished cattle, otherwise referred to as fed cattle. This is an important distinction because the U.S. produces the highest quality beef in the world, which drives demand from international partners to import our products. Over the course of the last decade, top export destinations for U.S. beef have been Japan, South Korea, China/Hong Kong, Mexico, and Canada. From 2015 to 2024, each of those respective markets imported roughly 25%, 21%, 15%, 12%, and 10%¹ of total U.S. beef exports. China/Hong Kong has especially turned into a large market for the U.S. following African Swine Fever outbreaks in 2018 that accelerated consumer demand shifts away from pork products and towards beef. By 2021, exports to China/Hong Kong nearly doubled, going from 11.5% of our total beef exports in 2020 to about 19% in 2021. With respect to international players in the global market for beef exports, by 2025, Brazil had the largest export volume, followed by Australia, the U.S., India, and Argentina.

Byproducts are another large source of value in the export market for U.S. beef. In 2024, byproducts and/or variety meats accounted for 22% of total volume in U.S. beef exports. Also referred to as hides and offal's, exports of these products add further value to the U.S. beef animal. The U.S. exports many of these products for the single fact that many byproducts of cattle are not common consumables for the U.S. consumer. Thus, we instead export them to countries and markets that will consume them and bring value back into the U.S. beef industry. Examples of these markets include tongues and lips that get shipped to Japan and Mexico, as well as livers, hearts, and kidneys getting sent to Egypt, South Africa, South America, Mexico, and Indonesia. It was estimated by the U.S. Meat Export Federation (USMEF) that overall sales of cattle byproducts

¹ Unless otherwise indicated, all statistics, totals, and other data were obtained from the United States Department of Agriculture (USDA) (2017) Quick Stats 2.0. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington DC.
<https://quickstats.nass.usda.gov/>

brought in an additional \$40+ per head to the value of U.S. cattle in 2021. From 2021 to 2024, the export value per fed head of cattle was estimated at an average of roughly \$400.

NONFED BEEF / IMPORT MARKET

The import market in the U.S. is characterized by the purchase of lower quality, lean beef products. Domestically, these lower quality products are similar to what you would receive out of dairy cows, beef cows, and bulls; because of this, much of the import market is distinguished as nonfed beef, or beef that's derived from cattle that didn't go through a grain finishing process. In other countries, grain finishing is a growing practice, however, the meat quality from these animals is often determined by other factors such as genetics and the type of feed they have access to. In the U.S., because our cattle industry is centered around the production of fed beef, the result is an excess supply of fat trimmings from our grain fed cattle. To derive added value out of our domestic herd, we import this leaner quality product to mix with our fat trimmings and produce ground beef. From 2015 to 2024, top import partners to the U.S. were Canada, Australia, Mexico, New Zealand, and Brazil; during those ten years, each of those market accounted for roughly 25%, 22%, 17%, 16%, and 9% of our total beef imports, respectively. Considering the growth observed out of those markets, imports of Brazilian beef has seen the largest increase over the ten-year period, rising roughly 20% on average each year compared to the approximate 5% increases seen out of Australia, Canada, and Mexico. Looking at international consumption trends, top markets for importing beef are China, the U.S., Japan, and South Korea.

LIVE CATTLE TRADE

The U.S. has a long history of importing cattle, primarily from Canada and Mexico, which is due largely to proximity allowing for greater ease of shipping cattle between countries. The number of cattle imported from Canada and Mexico, on an annual basis, as fluctuated. Over the last three decades, total cattle imports have ranged from about 1.4 million head in 2004 to nearly 2.8 million head in 1996 with an average of nearly 2.1 million head. In 2024, total cattle imports were just over 2.0 million head, in line with the historical average. Imports as a percentage of total cattle slaughter over the last three decades has ranged from 4% to nearly 8% with an average of 6%. In 2025, this percentage will likely fall to about 3% due to lower cattle imports from Mexico.

Cattle imports from Mexico over the last three decades have ranged from about half a million head in the mid-1990's to as much as 1.5 million head in 2012 with an average around 1.2 million head. Imported cattle from Mexico are typically feeder cattle destined for backgrounding operations or direct placement into feedlots. The number of cattle imported from Mexico in 2025 will decline to some of the lowest levels on record. This is due to the closure of the US and Mexico border as the threat of New World Screwworm (NWS) has move north through Mexico and is within a short distance of the US border. The livestock sector has not had to deal with NWS since the 1960's. With already tight cattle inventory levels, the threat of NWS heightens concerns regarding potential supply impacts to the US cattle sector.

Over the last three decades, cattle imports from Canada peaked at nearly 1.7 million head in 2002. By 2004, cattle imports from Canada dipped to 135 head in in the wake of bovine spongiform encephalopathy (BSE) cases in Canada. Since then, cattle imports from Canada have ranged from

the mid-600 thousand head to just over 1.2 million head. In the last five-years, cattle imports from Canada have averaged in the low-700 thousand head area. About three-quarters of the cattle imported from Canada have consisted of cattle weighing over 700 pounds and for immediate slaughter. The remaining cattle imports from Canada typically weigh less than 700 pounds and are likely destined for feedlot operations.

CONCLUSION

This paper considered several factors that can influence the dynamics underpinning global beef trading. Some of these factors include: consumer perception of producers' beef quality, consumers' global beef preferences, genetics and type of feed, insect and disease outbreaks, and proximity to the U.S. However, those factors, while important, are not the only ones to consider. The geopolitical environment, international exchange rates, and domestic trade policy are other factors beyond the scope of this paper but worth considering when analyzing global trade in the beef industry.

REFERENCES

Luke, Jamie. (2025, March 28). Variety meat exports provide value to the U.S. beef industry. Michigan State University Extension. <https://www.canr.msu.edu/news/variety-meat-exports-provide-value-to-the-u-s-beef-industry>

Proceedings, The Range Beef Cow Symposium XXIX
November 10 & 11, 2025, Cheyenne, Wyoming

**CO-PRODUCING RANGE BEEF COW RESEARCH WITH RANCHERS:
LESSONS LEARNED AND FUTURE OPPORTUNITIES**

Justin D. Derner
USDA-Agricultural Research Service
Center for Agricultural Resources Research
Rangeland Resources & Systems Research Unit

Mark Eisele, Kendall Eisele, Kaycee Eisele
King Ranch

INTRODUCTION

Conducting range beef cow research can be challenging due to several factors. These can include institutional logistical issues related to available scientific resources (e.g., size of experiment station, support personnel, funding), commitment of line management leadership to support of multiple year experiments, variability in weather/climate conditions over time, and maintaining relevance of research efforts to address priorities of ranchers. Science has been tremendously successful in increasing knowledge of mechanisms and processes associated with range beef cows from breeding/reproduction and production output aspects. However, much of this information has been delivered through traditional science-delivery methods including publishing papers in peer-reviewed scientific journals and then placement of this knowledge on “loading docks” for delivery of the scientific findings to the general public via interpretation and delivery through extension personnel, popular press articles, etc. (Cash et al., 2006; Naugle et al., 2020). Unfortunately, this science-delivery model is much less relevant today as the public has much more access to information through more contemporary methods (e.g., internet, podcasts, social media, etc.). As a result, the disconnect between management and science is a formidable challenge as these two are often not directly comparable endeavors (Provenza, 1991). While experimental range beef cow research in rangelands from the science perspective often focuses on specific aspects of management (e.g., grazing strategies, stocking rate, livestock distribution, etc.), ranchers make adaptive decisions for complex problems that involve variability in biophysical characteristics (soils, topography, plant communities, etc.), ecological, social, and economic/market factors, as well as weather/climatic variability, both within and across years (Knapp and Smith, 2001; Augustine, 2010). For example, ranchers employ experiential knowledge and adaptive management for drought conditions (Derner and Augustine, 2016), to improve livestock production (Derner et al., 2021), to focus on delivery of desired ranch-level objectives and outcomes (Derner et al., 2022), and proactively managing for changing weather and climatic conditions (Derner et al., 2023). Adaptive grazing management relies on flexibility, goal setting, identification of challenges, opportunities, and tradeoffs, and incorporates monitoring of outcomes through use of triggers for decision-making that facilitate timely adjustments of strategies (Jablonski et al., 2023). Yet, defining the contribution of adaptive management to range beef cow research is difficult because rancher decision-making is often excluded from experimental

research. This has hampered development of linkages between management and science which has been put forth as the major need for impactful research (e.g., Briske et al., 2011).

INTEGRATING RANCHERS AND SCIENTISTS IN CO-PRODUCTION RANGE COW BEEF RESEARCH

Integrating ranchers and scientists into co-production range cow beef research within a management-science partnership is difficult given the substantial variability associated with the commitment, ability, goals, and opportunities of ranchers and scientists to collaborate in such partnerships (Galvin et al., 2016; Reid et al., 2021; Wilmer et al., 2022). Ranchers and scientists bring different, and sometimes conflicting, attributes to the table for partnering in co-production research (Figure 1).

Range Beef Cow Co-production Research: Management – science partnerships

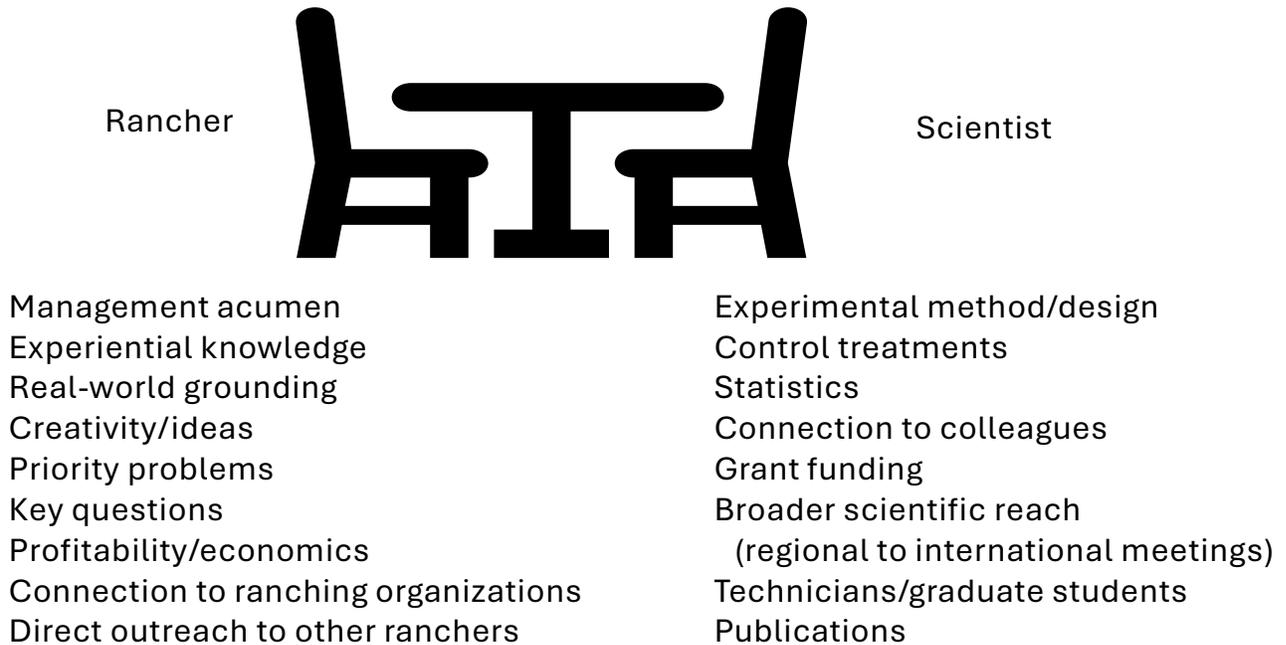


Figure 1. Attributes brought to the range beef cow co-production research table by ranchers and scientists in management-science partnerships.

For co-production range cow beef research, there are several challenges and opportunities associated with management-science partnerships (Table 1). First and foremost is the challenge of establishing trust - defined as a willingness of one entity to be vulnerable to the discretionary actions of another (Ford et al., 2020) - between the ranching and science entities. This is fundamental to establishing any partnership in natural resources (Coleman and Stern, 2018; Ford et al., 2020), but rises to another level with the co-production range cow beef research as trust is associated with reputation, communication, shared norms and values, cooperation/support, negative past behaviors, satisfaction with/quality of services, and fairness (Ford et al.,

2020). Roche et al. (2016) suggest the sustaining working rangelands for beef production is dependent upon trust-based partnerships that are focused on achieving both economic and ecological goals. Additional challenges for co-production range beef cow research include long-term (multi-year) commitments from both the rancher(s) and scientist(s), the line management support for the science, commitments of the ranch and/or science, impacts of weather/climatic variability and extreme events, as well as the fortitude to continue maintaining control treatments for the integrity of the scientific method.

Substantial opportunities exist for co-production range beef cow research associated with management-science partnerships. First, building on established trust between the entities provides for greater impact and relevancy of the research findings to a broader audience, increases the mutualistic creativity generated through synergy of the two entities, provides opportunities for rancher-led grant funding, and an increased ownership by the rancher of the research with time in a “living laboratory” (Wilmer et al., 2022, 2025).

Table 1. Challenges and opportunities with co-production range beef cow research associated with management-science partnerships.

Challenges	Opportunities
Establishing trust	Building on established trust
Long-term (multi-year) commitments	Greater impact from research findings
Institutional (line management) support	More creative ideas
Ranch/science respective commitments	Higher relevancy of findings
Weather logistics (drought, extreme events)	Rancher-led grant funding
Maintaining control treatments	Greater rancher ownership of research

Despite this, there are emerging successful multi-year examples of co-production research in rangeland ecosystems. Perhaps the most successful is the Collaborative Adaptive Rangeland Management (CARM) experiment in the semi-arid shortgrass steppe of northeastern Colorado (Wilmer et al., 2018; Fernández-Giménez et al., 2019; Augustine et al., 2024). Here, this decadal project (2014-current) integrates ranchers and scientists with non-governmental conservation organizations and state/federal land managers to address livestock production, vegetation, wildlife (mostly grassland bird habitat) and social learning objectives at a ranch-scale (2,600 ha or 6,400 acres) in the semiarid shortgrass steppe. Yearling steers, rather than range beef cows, are used as grazing animals for this project. Another successful collaborative adaptive management experiment is ongoing at the University of Nebraska-Lincoln’s Barta Brothers Ranch with yearling heifers ([Barta Brothers Ranch by Nebraska Institute of Agriculture & Natural Resources - Exposure](#)). Both examples emphasize collaborative partnerships among several entities for multiple loop learning opportunities (Fernández-Giménez et al., 2019) and have direct participatory efforts of these entities. To our knowledge, integrating ranchers and scientists in range cow beef research has been limited to the current collaboration between the King Ranch (Cheyenne, WY) and the USDA-Agricultural Research Service at the High Plains Grasslands Research Station.

FIRST DECADE – EARLY VS. LATE SEASON GRAZING - LESSONS LEARNED

Co-production range cow beef research between the King Ranch and the USDA-Agricultural Research Service began in late 2002 at the High Plains Grasslands Research Station, west of Cheyenne, WY. Range scientist Justin Derner arrived at the research station in March of that year with a charge of invigorating range cow beef research with ranchers. Conversations with the Wyoming Stock Growers Association leadership suggested a partnership with the King Ranch and the research station. Discussions among the King Ranch and the USDA-Agricultural Research Service line management were positive resulting in a formal five-year cooperative agreement that initialized the management-science partnership. Focused efforts were undertaken to address the challenges (Table 1) of co-production range beef cow research associated with management-science partnerships. Additional meetings and follow-up conversations between the King Ranch and Justin Derner were foundational to establish trust and have lines of communication for ranch and science commitments. The formal cooperative agreement addressed the long-term and line management support, as well as how operational logistics would be handled with the cattle and grazing at the research station during drought and other extreme events. Regarding maintaining control treatments, the mutual decision was for the control treatment to be season-long (early June to early October) grazing at the recommended stocking rate. A priority suggestion from the King Ranch for a grazing treatment was to evaluate cattle gains (cow, calf, and combined pair) in the early (June and July) part of the grazing season with those in the latter part (August and September). A key question was how would resting some pastures early in the grazing season for use later in the season affect livestock weight gains. Grazing cow-calf pairs early in the grazing season on one pasture and then shifting to another for late-season grazing could provide growing season rest to benefit plant species. How this management scenario affected cow, calf, and pair weight gains was a critical component to understanding if there were production tradeoffs (i.e., cattle gain reductions) resulting from emphasizing vegetation outcomes. The experimental design incorporated five northern mixed-grass (co-dominated by cool-season, C₃, and warm-season, C₄, perennial grasses) pastures with one season-long grazed at moderate stocking rate, and two pairs of two pastures with each pair having one pasture grazed early season (June and July) and the other late season (August and September). Here, one pair of pastures was grazed at the same moderate stocking rate and the other at a higher rate. Across the 10 years of this study (2003-2012), drought, average, and wet precipitation years occurred. Variability in gains among years was highest for cows and lowest for calves (Derner et al., 2022b). Calf gains were nearly split evenly between the early (55%) and later (45%) halves of the grazing season. In contrast, almost all of the cow gains occurred during the first half of the grazing season. On average, calf gains represented 74% to 78% of the cow-calf pair gains for the entire grazing season. Results from this co-produced range beef cow research demonstrated that cattle weight gains for cow-calf producers are only marginally affected when ranchers managed for desired vegetation rest periods in this rangeland ecosystem.

SECOND DECADE – ADAPTIVE, MULTI-PADDOCK GRAZING TO REDUCE RISK WITH THE POISONOUS PLANT PLAINS LARKSPUR - LESSONS LEARNED

The second decade of co-production range cow beef research between the King Ranch and the USDA-Agricultural Research Service (2013-2023) built on established trust and addressed other opportunities of management-science partnerships (Table 1). Additional cooperative agreements further cemented the commitments and institutional support. Conversations suggested maintaining

the seasonal grazing control treatment at a moderate stocking rate for evaluating long-term effects (e.g., see Irisarri et al., 2025). A priority question for ranchers in the region, including the King Ranch, was if employing adaptive, multi-paddock grazing (AMP) could reduce risk of livestock losses (both in terms of production and death loss) associated with the poisonous plant plains larkspur (*Delphinium geyeri*). This plant is very toxic in the vegetative stage, so early season grazing (in June) can be problematic for ranchers when this species is present and chemical control efforts are costly (Kersh et al., 2024). One alternative that was mutually agreed upon to explore was to each year adaptively choose the pasture with the lowest amount of plains larkspur to begin the grazing season and then rotate among the remaining four pastures. This would also allow for spot herbicide treatments in pastures not being grazed with more abundance of plains larkspur. The control treatment remained the season-long (early June to early October) grazing at the recommended stocking rate. We continued to evaluate cattle gains across the grazing season in both the control and AMP grazing treatments (consisting of four pastures) at the moderate stocking rate. Calf gains were reduced by almost 7% and cow gains by 23% for the AMP grazing treatment across the decade of drought, average, and wet conditions (Dermer et al., *in prep*). Calf gains strongly responded as spring precipitation increased in the control, season-long grazing treatment. Results from this co-produced range beef cow research demonstrated that opportunities for increased calf weight gains with greater spring precipitation are sacrificed with AMP grazing in this rangeland ecosystem as stock densities are higher (see Augustine et al., 2020 for reduced yearling steer gains with high stock density with AMP grazing), which alters grazing behavior (Augustine et al., 2023) resulting in lower dietary quality (Jorns et al., 2024). The use of AMP grazing provides benefits to reduce risk and death losses from the poisonous plant plains larkspur as well as opportunities to alter timing of grazing among pastures over years but does have tradeoffs with calf production in the northern mixed-grass prairie.

THIRD DECADE – PRECISION LIVESTOCK TECHNOLOGIES - FUTURE OPPORTUNITIES

The third decade of co-production range cow beef research between the King Ranch and the USDA-Agricultural Research Service (2024-forward) enters an era to capitalize on opportunities of management-science partnerships (Table 1). Mutual efforts are addressing incorporation of more creative ideas, greater impact and higher relevance of research with the next generation of King Ranch becoming more involved in the co-production research. This decade is exploring the emerging robust precision livestock technologies associated with on-animal sensors for animal activities, health, and efficiencies. Rather than previous experiments that were intentionally long-term (decadal) to capture the wide-ranging weather/climatic variability across years, current efforts are shorter-term to capture the emerging, and ever-expanding, precision livestock technologies. Longitudinal study emphasis will remain, but the expanding trust now empowers the King Ranch with maintaining the long-term cow data for assessments of lifetime cow productivity. Current technologies being assessed include solar ear tags that provide GPS locations and grazing algorithms for activities (e.g., [xTpro - GPS Ear Tags for Cattle](#)) that will facilitate linkage of foraging behavior in cows with diet quality and weight gains (see Augustine et al., 2025). Deployment was undertaken with 74 replacement heifers in the summer of 2025 on the King Ranch to assess grazing distributions (Figure 2) to determine if virtual fencing would be advantageous to employ after learning animal distributions.

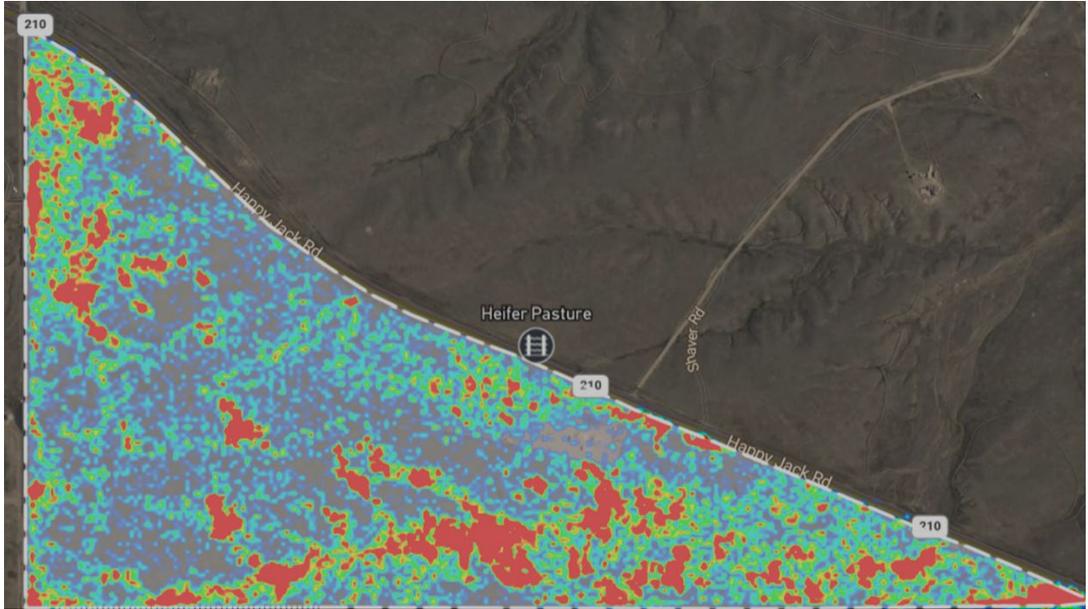


Figure 2. Heat map from May 22-28, 2025, of replacement heifer GPS locations from the 701x xTpro solar-powered ear tag (<https://www.701x.com/xtpro-tag>). Warmer colors (e.g., orange) indicate locations of higher use and grey color indicates low use.

The ear tags also provide detection of estrous that can assist ranchers with timing of breeding at the individual animal level, and placement of these tags in four bulls provided assessments of bull movement and mounting events (Figure 3).

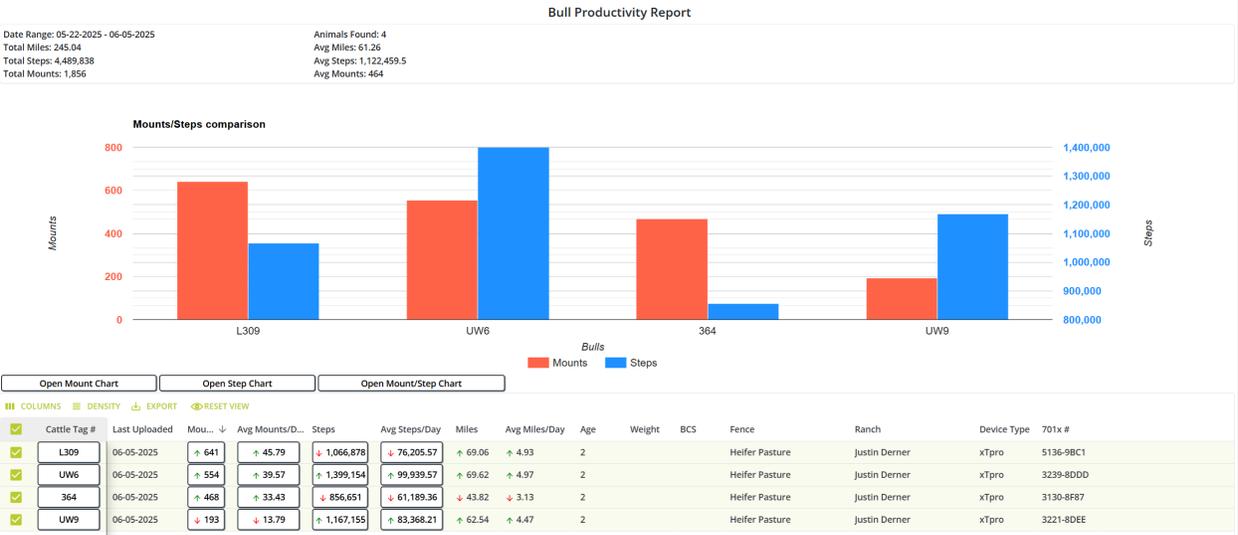


Figure 3. Bull productivity (mounts and steps taken) report from May 22 to June 5, 2025, for four bulls in with 74 replacement heifers. Data obtained through algorithms with the 701x xTpro solar-powered ear tag (<https://www.701x.com/xtpro-tag>).

Two Green Feed pasture systems (<https://www.c-lockinc.com/products/emissions-monitoring/greenfeed-pasture-system>) were deployed to determine in 2024-2025 to obtain individual animal metabolic gas (e.g., CO₂, CH₄, O₂, and H₂) fluxes for possible assessments of

nutritional efficiency that may be helpful in replacement heifer selections. Ongoing experiments are collecting longitudinal data from heifer calves of 1st and 2nd calf heifers during 1) post-weaning in fall 2024, 2) backgrounding over the 2024-2025 winter, 3) the 2025 summer grazing season as either a) replacement heifers exposed to bulls or b) non-replacement heifers, and 4) the 2025 fall period preceding calving.



Figure 4. Photo of a GreenFeed Pasture System (<https://www.c-lockinc.com/products/emissions-monitoring/greenfeed-pasture-system>) used to obtain individual animal metabolic gases (e.g., CO₂, CH₄, O₂, and H₂).

CONCLUSIONS

Conducting co-production range cow beef research between the King Ranch and the USDA-Agricultural Research in multi-decadal management-science partnership has addressed challenges and embraced opportunities (Table 1) from this novel approach to science. Lessons learned included how to effectively incorporate attributes brought to the range beef cow co-production research table by ranchers and scientists in a long-term (multi-decadal) management-science partnership (Figure 1). The co-produced research on early vs. late grazing seasons and AMP grazing provided results highly applicable and relevant to ranchers in the region. Future opportunities with co-production research are addressing the emerging precision livestock technologies for use by ranchers to address key priorities and solve problems at the ranch-scale in the northern mixed-grass prairie rangeland ecosystem.

REFERENCES

Augustine, D.J., 2010. Spatial versus temporal variation in precipitation in a semiarid ecosystem. *Landscape Ecology* 25:913-925.

- Augustine, D.J., Derner, J.D., Fernández-Giménez, M.E., Porensky, L.M., Wilmer, H., and Briske, D.D., 2020. Adaptive, multipaddock rotational grazing management: a ranch-scale assessment of effects on vegetation and livestock performance in semiarid rangeland. *Rangeland Ecology & Management* 73:796-810.
- Augustine, D.J., Kearney, S.P., Raynor, E.J., Porensky, L.M., and Derner, J.D., 2023. Adaptive, multi-paddock, rotational grazing management alters foraging behavior and spatial grazing distribution of free-ranging cattle. *Agriculture, Ecosystems & Environment* 352:108521.
- Augustine, D.J., Derner, J.D., Porensky, L.M., Hoover, D.L., Ritten, J.P., Kearney, S.P., Ma, L., Peck, D., Wilmer, H. and CARM Stakeholder Group, 2024. The LTAR grazing land common experiment at the Central Plains Experimental Range: Collaborative adaptive rangeland management. *Journal of Environmental Quality* 53:904-912.
- Augustine, D.J., Reed, M., Kearney, S.P., Porensky, L.M., Scasta, J.D., Pellatz, D.W., and J.D. Derner., 2025. Linking foraging behavior of free-ranging, lactating beef cows with diet quality and weight gain in semi-arid rangeland. *Applied Animal Behaviour Science* 292: 106802.
- Boyd, C.S. and Svejcar, T.J., 2009. Managing complex problems in rangeland ecosystems. *Rangeland Ecology & Management* 62:491-499.
- Briske, D.D. [ed]. 2011. Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps. United States Department of Agriculture, Natural Resources Conservation Service. 429 p.
- Briske, D.D., Sayre, N.F., Huntsinger, L., Fernández-Giménez, M., Budd, B. and Derner, J.D., 2011. Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. *Rangeland Ecology & Management* 64:325-334.
- Cash, D.W., Borck, J.C. and Patt, A.G., 2006. Countering the loading-dock approach to linking science and decision making: comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Science, Technology, & Human Values* 31:465-494.
- Coleman, K. and Stern, M.J., 2018. Exploring the functions of different forms of trust in collaborative natural resource management. *Society & Natural Resources*, 31:21-38.
- Derner, J.D. and Augustine, D.J., 2016. Adaptive management for drought on rangelands. *Rangelands* 38:211-215.
- Derner, J.D., Augustine, D.J., Briske, D.D., Wilmer, H., Porensky, L.M., Fernández-Giménez, M.E., Peck, D.E. and Ritten, J.P., 2021. Can collaborative adaptive management improve cattle production in multipaddock grazing systems? *Rangeland Ecology & Management* 75:1-8.
- Derner, J.D., Budd, B., Grissom, G., Kachergis, E.J., Augustine, D.J., Wilmer, H., Scasta, J.D. and Ritten, J.P., 2022a. Adaptive grazing management in semiarid rangelands: An outcome-driven focus. *Rangelands* 44:111-118.
- Derner, J.D., Roberts, K., Eisele, M., Wilmer, H., Mortenson, M., Freeman, P. and Lockman, R., 2022b. King Ranch: Ranching on the edge. *Rangelands* 44:411-417.
- Derner, J.D., Wilmer, H., Stackhouse-Lawson, K., Place, S. and Boggess, M., 2023. Practical considerations for adaptive strategies by US grazing land managers with a changing climate. *Agrosystems, Geosciences & Environment* 6:e20356.
- Fernández-Giménez, M.E., Augustine, D.J., Porensky, L.M., Wilmer, H., Derner, J.D., Briske, D.D. and Stewart, M.O., 2019. Complexity fosters learning in collaborative adaptive management. *Ecology and Society* 24:29.

- Ford, J.K., Riley, S.J., Lauricella, T.K. and Van Fossen, J.A., 2020. Factors affecting trust among natural resources stakeholders, partners, and strategic alliance members: a meta-analytic investigation. *Frontiers in Communication* 5:9.
- Galvin, K.A., Reid, R.S., Fernandez-Gimenez, M.E., ole Kaelo, D., Baival, B. and Krebs, M., 2016. Co-design of transformative research for rangeland sustainability. *Current Opinion in Environmental Sustainability* 20:8-14.
- Irisarri, J.G.N., Cipriotti, P.A., Sardiña, L.C., Mortenson, M. and Derner, J.D., 2025. Influences on calf productivity during five decades of cow-calf grazing of northern prairie. *Animal* 101557.
- Jablonski, K.E., Derner, J.D., Bailey, D.W., Davies, K.W., Meiman, P.J., Roche, L.M., Thacker, E.T., Vermeire, L.T. and Stackhouse-Lawson, K.R., 2024. Principles for successful livestock grazing management on western US rangelands. *Rangelands* 46:35-41.
- Jorns, T.R., Derek Scasta, J., Derner, J.D., Augustine, D.J., Porensky, L.M., Raynor, E.J. and CARM Stakeholder Group, 2024. Adaptive multi-paddock grazing management reduces diet quality of yearling cattle in shortgrass steppe. *The Rangeland Journal* 45:160-172.
- Kersh, A.J., Fraley, H.M., Scasta, J.D., Derner, J.D., Lima, P.D.M.T. and Stewart, W.C., 2024. Sheep dietary preferences in targeted grazing: demographic, management, and weather effects in northern mixed-grass prairie. *Frontiers in Veterinary Science* 11:1502948.
- Knapp, A.K. and Smith, M.D., 2001. Variation among biomes in temporal dynamics of aboveground primary production. *Science* 291:481-484.
- Naugle, D.E., Allred, B.W., Jones, M.O., Twidwell, D. and Maestas, J.D., 2020. Coproducing science to inform working lands: The next frontier in nature conservation. *BioScience* 70:90-96.
- Provenza, F. D. 1991. Viewpoint: range science and range management are complementary but distinct endeavors. *Journal of Range Management* 44:181-183.
- Reid, R.S., Fernández-Giménez, M.E., Wilmer, H., Pickering, T., Kassam, K.A.S., Yasin, A., Porensky, L.M., Derner, J.D., Nkedianye, D., Jamsranjav, C. and Jamiyansharav, K., 2021. Using research to support transformative impacts on complex, “wicked problems” with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems* 4:600689.
- Roche, L.M., Schohr, T.K., Derner, J.D., Lubell, M.N., Cutts, B.B., Kachergis, E., Eviner, V.T. and Tate, K.W., 2015. Sustaining working rangelands: insights from rancher decision making. *Rangeland Ecology & Management* 68:383-389.
- Wilmer, H., Derner, J.D., Fernández-Giménez, M.E., Briske, D.D., Augustine, D.J. and Porensky, L.M., 2018. Collaborative adaptive rangeland management fosters management-science partnerships. *Rangeland Ecology & Management* 71:646-657.
- Wilmer, H., Schulz, T., Fernández-Giménez, M.E., Derner, J.D., Porensky, L.M., Augustine, D.J., Ritten, J., Dwyer, A. and Meade, R., 2022. Social learning lessons from collaborative adaptive rangeland management. *Rangelands* 44:316-326.
- Wilmer, H., Spiess, J., Clark, P.E., Anderson, M., Burns, A., Crootof, A., Fanok, L., Hruska, T., Mincher, B.J., Miller, R.S. and Munger, W., 2025. Collaborative adaptive management in the Greater Yellowstone Ecosystem: A rangeland living laboratory at the US Sheep Experiment Station. *Sustainability* 17:3086.

COST OF PRODUCTION IN THE COW-CALF SECTOR

Brandon Dodd
Livestock Marketing Information Center
Colorado State University

INTRODUCTION

In a cow-calf operation, cost of production (COP) can be defined by the culmination of expenses paid or unpaid on factors such as labor, fuel and repairs, feed, veterinary care, pasture or lease costs, depreciation on equipment and facilities, property taxes and insurance, and the opportunity cost of capital (e.g., cows, land, and machinery). Keeping these costs visible in an operation matters because most profit swings occur at the margin, whether that be on timing decisions, like when to buy or sell; on management choices, like what to feed through winter; or on whether overhead is spread across enough productive cows. Prior proceedings of the Range Beef Cow Symposium (RBCS) have explored discussions that define cost of production and factors to consider (e.g., Berger, 2011; Walker, 2013) as well as methods for cost reduction and revenue improvement (e.g., RBCS, 2023, p. 2; Whittier et al., 2013). This report acknowledges the work of these past authors and intends only to revisit a couple of topics important to cow-calf operators: rangeland/grazing access and sourcing replacement heifers.

THE SUBJECTIVITY OF COST OF PRODUCTION

In any business venture, costs are complicated. For cow-calf producers, this is especially true. The producer or practitioner often has to consider the management of animal biology, like how many breeding cows to maintain, how many bulls to run per cow, what to define the useful life of their bulls and cows as, identify what their weaning percentages and weights are, and also identify what their desired retention and cull rates are. At the same time, producers must manage the environmental component of their farm or ranch. These components could include, for instance, identifying a management strategy behind whether their pasture acres are dryland or irrigated, understanding what typical grass production looks like in a year, and identifying what types of grass are being grazed. This leads into more complex cross-area questions like, what are the nutritional requirements of cow-calf pairs, and how does the type of grass translate into stocking densities and growth rates? The list goes on. These components are but a handful of dozens that matter when deriving a true COP number for cow-calf operations.

Due to the subjectivity that this induces, a number of resources have been developed over the years to assist ranchers with estimating these costs. Among allied land-grant university's Extension programs in the Range Beef Cow Symposium (i.e., Colorado State University, South Dakota State University, University of Nebraska-Lincoln, and University of Wyoming), are state specific decision support tools, along with enterprise budgets that should be sought after in the cost accounting process. Even then, producers should take national, regional, and state-specific

estimates with a grain of salt. All costs are relative and subject to specific geographic markets, environments, breeds, levels of land and capital ownership, and the management style of the given producer.

GRASS-CAST: A GRASSLAND FORECASTING RESOURCE

Shedding light on an established tool while providing an example of the subjectivity of cost accounting, every year throughout the grassland growing season, a collaboration between Colorado State University, the United States Department of Agriculture-Agricultural Research Service, the National Drought Mitigation Center at the University of Nebraska-Lincoln, and the University of Arizona, produces annual grassland biomass forecasts for the Great Plains and Southwestern regions of the U.S. In these forecasts, site-specific estimates on the percentage changes of Aboveground Net Primary Production (ANPP) are provided in relation to their associated 36-year average. The origins of this program, named Grass-Cast, were to help ranchers address difficult questions behind how much grass will be available for livestock to graze during upcoming summers, effectively reducing economic uncertainties. While the forecasts cannot discern between desirable and undesirable forage species, the information still provides the producer with valuable information.

For example, based on the annual production of grassland per acre in an area, the type of grass being grazed, the grazing efficiency desired and/or required (e.g., 50% vs. 25%, winter vs. summer), and the given herds nutritional intake requirements, a producer can calculate rough estimates of how many days a cow-calf pair can be held on an acre of ground; scaling is also possible based on increased numbers of pairs and acres. Using methods like this can provide producers with an idea of what animal unit days (AUD) they will or will not have to pay for other supplemental feeds (e.g., hay, mineral, protein). Producers should keep in mind the specificity of geography, however, as substantial variation occurs. For instance, statewide 36-year averages of total ANPP per acre per year in Colorado and Wyoming range from the low-to-high 800-pound range, while Nebraska and South Dakota see roughly 1,900 and 2,500 pounds per acre per year, respectively. Within Colorado alone, county-level averages range from just above 400 pounds to near 1,500 pounds per acre per year. A reminder here is that these production estimates are for non-irrigated grasslands, and they do not account for specific range management practices. For more detail on the biomass forecasts themselves, information and outlooks can be found at the following link: <https://grasscast.unl.edu/>.

PURCHASE OR RAISE REPLACEMENT HEIFERS

Another pivotal question in cow-calf operations is whether to purchase or develop replacement heifers. For the purposes of this article, significant factors including genetic selection and herd quality are acknowledged but will largely be neglected so focus can instead be on the general economics of the raise versus buy decision. A simple way to frame this is by asking what is the cost per confirmed pregnant heifer under each option this year? That single metric, computed similarly for raise or buy, keeps the decision more apples-to-apples.

In a purchasing decision, a producer should consult multiple sources of information when identifying replacements. If the producer is looking to buy bred heifers, check how long they have been bred, the sire's breed, and the fertility/growth records of both the sire and dam. If interested

in virgin heifers, recognize that conception rates typically fall between 80-95% over a 45–70-day season (Berger and Funston, 2013), and final pregnancy rates are often lower than that. Pricing opens accordingly ensures the average cost per bred heifer reflects those open rates. Additionally, because development costs are incurred with virgin heifers, whether she becomes pregnant or not, an open heifer will raise the average cost of the heifers that do become pregnant. As a result, purchasing bred heifers at roughly the average development cost of pregnant heifers can be a reasonable alternative. There are also considerations for first-calf heifers, which undergo not only the stress of calving and lactation but also growing into a mature frame. If their nutrient requirements wane, rebreeding rates will decline, which will reduce overall herd productivity and profitability in the long run (Griffith and Rhinehart, 2024). A useful general rule is that if local bred-heifer prices are at or below your calculated cost per developed bred heifer, including opens, buying bred heifers can be the lower-risk, lower-cost path in a given year. These same concepts hold when raising heifers on-farm.

Complementing those purchasing considerations, the raise or buy choice should be priced to include opportunity costs. If home-raised heifers are retained, consider the current market value of that animal, or the revenue you forgo by not selling them, and add in any direct costs (i.e., feed, health, labor), required resources (i.e., pasture, facilities, management time), interest, taxes, and any extra breeding expenses. That opportunity cost is often large enough to change the decision entirely when calf prices or interest rates are high, so making sure it's built into the analysis rather than being an afterthought is important. Cost structures and goals differ from operation to operation, so a universal best answer that fits all does not exist. Regarding subjectivity, remember that economies of size matter; smaller herds often pencil out better buying bred heifers, while larger herds can spread fixed labor and management over more animals and reduce per head costs by developing their own (Cleer, 2006).

For a bottom line, apples-to-apples comparison when making this decision, build an enterprise budget that includes opportunity cost, compute the cost per pregnant heifer for each alternative practice (i.e., raise on-farm or purchase), and choose the option that has the lowest expected cost while best fitting for your management capacity and genetic goals. This budgeting exercise is something that should be considered every year, and several tools are available to assist answering these complex questions with state Extension programs.

CONCLUSION

Tools like Grass-Cast and the many decision support tools available through university Extension programs aid answering questions around cost of production for cow-calf producers. Subjectivity remains the complication, however, in attempting to have these conversations on larger scales. Every operation has a different management strategy, different environment, different breeding and genetic program, etc. Investing the time each year to understand operational standings at the margin is critical for increasing efficiency and profitability.

REFERENCES

- Berger, Aaron L., "Calculating Unit Costs of Production and Using the Information for Enterprise Analysis and Decision Making on the Ranch" (2011). Range Beef Cow Symposium. 282. <https://digitalcommons.unl.edu/rangebeefcowsymp/282>
- Berger, A. L. & Funston, R. N. (2013). *Reducing Replacement Heifer Development Costs Using a Systems Approach* (G2215). University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Sources. <https://extensionpubs.unl.edu/publication/g2215/2013/pdf/view/g2215-2013.pdf>
- Cleere, J. (2006). *Buying vs. Raising Replacement Heifers* (ANSC-PU-043). Texas A&M AgriLife Extension. <https://cdn-de.agrilife.org/extension/departments/ansc/ansc-pu-043/publications/files/buying-vs-raising-replacement-heifers.pdf>
- Griffith, A. P. & Rhinehart, J. D. (2024). *Raising Versus Purchasing Replacement Heifers: Production, Value and Cost Considerations* (W 1283). University of Tennessee Institute of Agriculture, UT Extension. <https://utia.tennessee.edu/publications/wp-content/uploads/sites/269/2024/11/W1283.pdf>
- "Range Beef Cow Symposium XXVII Proceedings, 2023, Loveland, Colorado" (2023). Range Beef Cow Symposium. 378. <https://digitalcommons.unl.edu/rangebeefcowsymp/378>
- Walker, Julie, "Managing Annual Cow Costs" (2013). Range Beef Cow Symposium. 315. <http://digitalcommons.unl.edu/rangebeefcowsymp/315>
- Whittier, Jack; Sewell, James; Blair, Ed; and Ramsay, Chip, "Producer Panel – Managing Cow Costs To Improve Profitability" (2013). Range Beef Cow Symposium. 314. <http://digitalcommons.unl.edu/rangebeefcowsymp/314>

INFLUENCE OF NUTRITIONAL MANAGEMENT ON BULL FERTILITY

Pedro L. P. Fontes¹, Lucas Melo-Gonçalves¹, Saulo M. Zoca²

¹Department of Animal and Dairy Sciences, University of Georgia, Athens, GA

²Department of Animal Science, University of Tennessee, Knoxville, TN

INTRODUCTION

The main factor influencing productivity in cow-calf operations is the percentage of calves weaned on a yearly basis. There are several aspects related to the cow herd that increase calf crop percentage, such as cow body condition score, days post-partum at the onset of the breeding season, and parity (Lamb and Mercadante, 2016). Moreover, bull optimal fertility is also required to achieve acceptable pregnancy rates within the breeding season. The ability of a bull to successfully breed cows is associated with several factors, such as structural musculoskeletal soundness, libido, and semen quality (Wiltbank and Parish, 1986). Considering that over 85% of cow-calf operations in the United States utilize only natural service as their main breeding strategy (USDA, 2020), male reproductive failures have an extensive impact on cow herd reproductive efficiency. In the context of assisted reproductive technologies, male subfertility accounts for reproductive failures and decreased pregnancy rates in artificial insemination and decreased embryo production in both in vivo and in vitro embryo transfer programs (Vasconcelos et al., 2017; Ortega et al., 2018; Zoca et al., 2020).

Over the last decade, studies have demonstrated that the paternal influence on fertility and pregnancy success in cattle goes beyond fertilization. For example, bulls that have decreased fertility based on Sire Conception Rates (SCR) estimates had similar cleavage rates in vitro; however, the percentage of embryos that successfully developed to the blastocyst was decreased compared with bulls classified as having high SCR. Similarly, Franco et al. (2018) evaluated the impact of sire on pregnancy loss and observed that cows bred by certain bulls had greater chances of undergoing pregnancy loss after a pregnancy had been initially confirmed via ultrasonography. Intriguingly, sires utilized in these studies passed a breeding soundness examination (BSE) and semen quality control analyses, indicating that variations in sire fertility go beyond defects traditionally detected in conventional semen analyses (Koziol and Armstrong, 2018). Therefore, the development and utilization of novel methods of semen analysis can provide further insight into estimating sire intrinsic fertility or the impact of management practices (i.e., nutrition) on semen quality. Herein, we provide a general overview of studies investigating the impact of sire over conditioning on fertility using traditional and novel methods to investigate male fertility. Moreover, a summary of the practical impacts of sire over conditioning on herd fertility is also provided.

OVER CONDITIONED SIRES IN THE BEEF INDUSTRY

Sire over-conditioning is commonly observed in the beef industry. Because both pre- and postweaning growth are critical for profitability, producers seek to identify bulls with superior genetics for weaning and yearling weights. Nevertheless, bulls are commonly maintained on high-energy diets to maximize genetic potential at yearling weight collection and are often kept on these diets until sale. Several Extension programs and bull development stations across the U.S. have reported the general preference of bull buyers for bulls with high rates of average daily gain (ADG) during their growth and development phase. In fact, bull buyers prioritize growth-related traits versus feed efficiency traits such as feed-to-gain ratio (F:G) or residual feed intake (RFI; Oosthuizen et al., 2018). In a previous report from our group, we evaluated the relationship between the growth performance of 829 bulls enrolled in the University of Florida's NFREC Bull Test and sale prices at the NFREC Bull Test Sale. A positive correlation (Figure 1) was observed between sale prices and ADG ($r = 0.23$; $P < 0.01$), body weight (BW) per day of age ($r = 0.31$; $P < 0.01$), and BW at the end of the test ($r = 0.46$; $P < 0.01$; Oosthuizen et al., 2018). Moreover, there was no correlation between sale price and RFI or F:G ($P > 0.20$). Another factor that encourages seedstock producers to increase energy intake during sire development is the neuroendocrine regulatory effect of these dietary strategies on pubertal development. Similar to what has been thoroughly shown in heifers, sires that are exposed to high-energy diets achieve puberty earlier. Although the neuroendocrine changes associated with puberty are less understood in young bulls compared with heifers (Cardoso et al., 2018.; Kenny and Byrne, 2018), enhancing the early life plane of nutrition of bulls stimulates a complex biochemical interplay involving metabolic and neuroendocrine signaling that culminates in earlier onset of sexual maturation (Kenny and Byrne, 2018). Yet, most bulls from British breeds reach puberty prior to yearling body weight assessments, and continuing to feed bulls high-energy diets later in development has minor effects on advancing puberty (Byrne et al., 2018).

EPIDEMIOLOGICAL EVIDENCE FOR THE IMPACT OF SIRE OVER-CONDITIONING ON SEMEN QUALITY

As previously mentioned, over-conditioned bulls are attractive to bull buyers, and body weight gain is positively correlated with greater bull sale prices. Yet, over-conditioning might have negative consequences for semen quality and skeletal muscle soundness. Although studies have shown that the post-puberty negative energy balance impairs reproduction in both heifers and bulls, research has been done evaluating the impacts of excessive growth and fat deposition on bull fertility outcomes, evaluating techniques that are commonly utilized in breeding soundness examination. Recently, our group conducted an epidemiological study evaluating the relationship between subcutaneous backfat thickness (SCBF) and BSE outcomes in yearling beef bulls (Smith et al., 2025). Records from 710 Angus and SimAngus bulls developed under standard industry practices at bull evaluation programs in the University of Georgia and Tennessee were retrospectively analyzed. Bulls were classified into cohorts based on SCBF estimates obtained by carcass ultrasonography, with comparisons made between bulls in the upper (top 10-20%), middle (60-80%), and lower (bottom 10-20%) percentiles of the population. Bulls with greater SCBF were heavier and had increased ribeye area and intramuscular fat. Increased SCBF was associated with a reduction in the percentage of morphologically normal sperm, driven by an increase in both

primary and secondary abnormalities. Thus, a greater proportion of bulls with elevated SCBF were classified as deferred during their first BSE, and odds ratio analyses indicated that high-SCBF bulls had more than three times greater odds of failing compared with bulls in the middle range. These results demonstrate that natural variation in adiposity within bulls managed under the same diet is associated with impaired semen quality and reduced likelihood of passing a BSE at yearling age.

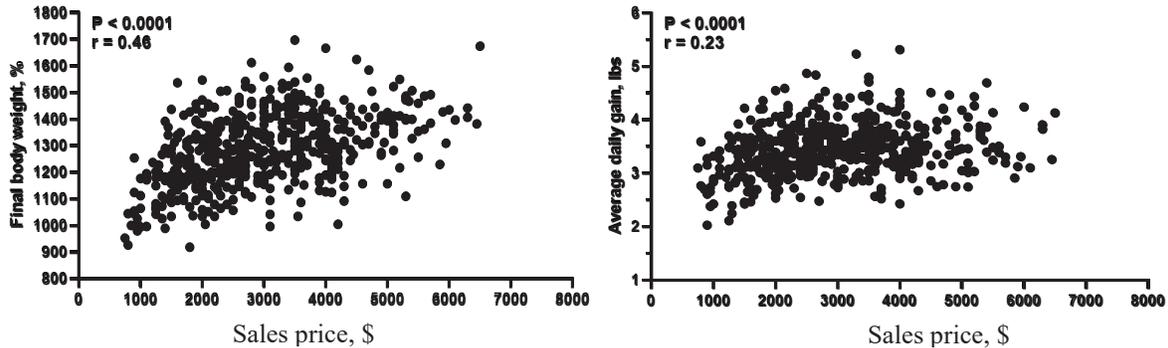


Figure 1. Final BW and ADG were significantly correlated with the sale price. Residual feed intake (RFI) and feed-to-gain ratio (F: G) were not associated with the sale price (Adapted from Oosthuizen et al., 2018).

IMPACT OF SIRE OVER-CONDITIONING ON SEMEN QUALITY IN CONTROLLED STUDIES

Previously mentioned observational studies indicated a negative relationship between bull over conditioning and the ability of bulls to have a satisfactory breeding soundness examination. More specifically, these studies indicated a negative impact of excessive body weight gain and fat deposition on semen quality. While these studies were observational and lacked the controlled experimental conditions necessary to isolate the effect of nutritional status on semen parameters, controlled studies using different diets also show a detrimental effect of diet-induced highly anabolic conditions on semen quality. Coulter et al. (1997) evaluated the impact of feeding young bulls a moderate-gain diet primarily comprised of forage (Control) versus a high-energy diet consisting of 80% concentrate and 20% forage (High Gain) for a period of 168 days after weaning. As expected, bulls fed the High Gain diets were heavier by the end of the feeding period and had greater backfat thickness compared with Control bulls. Notably, bulls in the High Gain diet had a greater percentage of secondary sperm defects (28.7% vs. 9.9%) and decreased average sperm motility (44.5% vs. 53.4%) compared with Control bulls (Figure 2.A). Moreover, the High Gain bulls also had greater scrotal circumference and decreased changes in scrotal surface temperature gradient (measured with infrared camera; Figure 2.B) from the top portion of the scrotum compared with the bottom portion of the scrotum. These results indicate that High Gain bulls may have experienced impaired testicular thermoregulation, potentially associated with increased fat deposition in the neck region of the scrotum, which could explain the decrease in semen quality. Notably, both impaired thermoregulation and highly anabolic diets are associated with excessive production of reactive oxygen species (ROS) in sperm cells, which can damage sperm function and reduce male fertility (Houffly et al., 2018; Barbagallo et al., 2021). Anabolic diets have been

shown to increase sperm ROS concentrations in bulls (Dahlen et al., 2022), and oxidative stress is considered a major contributor to the observed reduction in sperm motility, morphology, and fertilization capacity. Supporting this mechanism, previous studies using scrotal insulation demonstrated that increased testicular temperature induces oxidative stress, which is associated with decreased sperm motility, reduced proportions of morphologically normal sperm, impaired sperm chromatin structure, and reduced fertilization and blastocyst formation during in vitro embryo production (Ferrer et al., 2020; Lucio et al., 2016; Mitchell et al., 2010).

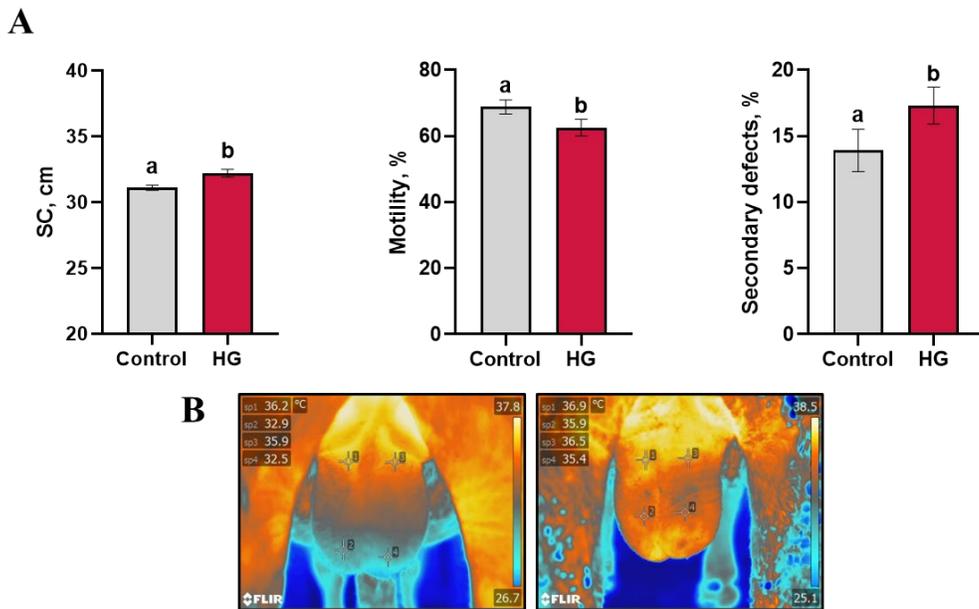


Figure 2 A) Effect of inclusion of high-gain diets for young bulls and its impact on scrotal circumference, sperm progressive motility, and sperm secondary defects. Adapted from: Coulter et al. (1997). B) Representation of infrared thermal imaging of the scrotum with different gradients of scrotal surface in young beef bulls.

IMPACT OF SIRE OVER-CONDITIONING ON SEMEN QUALITY USING NOVEL ESTIMATES OF SIRE FERTILITY

Veterinarians can assess semen quality of bulls prior to the breeding season and the potential of semen samples to generate pregnancies based on sperm motility and morphology through a traditional BSE (Wiltbank et al., 1986; Neville et al., 1988; Koziol and Armstrong, 2018). While BSE is a convenient and accurate tool to recognize bulls with limited fertility, the ability of current breeding soundness examination standards to recognize sires with suboptimal fertility is partial (DeJarnette, 2005). Therefore, novel techniques are being utilized to further understand semen quality and estimate male fertility. Examples include, but are not limited to, computer assisted semen analysis (CASA) and flow cytometry (DeJarnette et al., 2022). Computer-assisted sperm analysis utilizes specialized software and digital imaging to assess various parameters of sperm movement, enabling the possibility to objectively assess sperm kinematics (Horst et al., 2018). Hence, CASA provides a more thorough description of sperm cell movement compared with subjective estimates of sperm motility utilized during traditional BSE. Flow cytometry is a technology that allows for fast multi-parametric analyses of large numbers of cells individually. The use of this technology for evaluating sperm cells in semen analysis has provided further

information on the physical and functional properties of sperm cells (Graham et al., 1990). Flow cytometry has allowed scientists, genetic companies, and veterinarians to gain insight into sperm cell plasma membrane, chromatin, and acrosome integrity, as well as sperm capacitation status, mitochondrial activity, and oxidative stress (Rosa et al., 2023; Zoca et al., 2020; 2023).

Recent studies have also indicated that sperm cells not only play a role in fertilization but also influence the subsequent embryo development and pregnancy establishment. Although fertilization rates are relatively optimum in beef cattle (> 80%; Santos et al., 2004), pregnancy rates 30 days after breeding in beef females that are exposed to artificial insemination generally range between 40 and 60% (Lamb et al., 2010), indicating that pregnancy loss between fertilization and the first pregnancy diagnosis occurs in a considerably high proportion of cows and heifers (Reese et al., 2020). Most research on embryonic mortality in cattle has focused on factors associated with the female. More recently, research from other species has shown that sperm play an important role in early embryonic development and postfertilization infertility (Daigneault, 2021). In humans, observation studies reported that couples where males were obese (body mass index > 28) had decreased in vitro embryo production during fertility treatment and decreased pregnancy rates after embryos were transferred (Yang et al., 2016). Similar results were found in mice, where paternal high-fat diets were also related to a decrease in in vitro embryo production and impaired pregnancy establishment (Mitchell et al., 2011).

Our group has focused on utilizing these new technologies to further understand the impact of high-energy diets on the fertility of beef bulls. Moreover, we are currently investigating the consequences of these diets on embryo development and pregnancy establishment. In a recent study (Seekford et al., 2023), mature bulls (n = 8) that had previously passed a breeding soundness examination were randomly assigned to either receive a diet designed to elicit an average daily gain of 4 lbs/d (High Gain) or a diet designed to maintain body weight (Control). Bulls were fed their respective diets individually for 67 days, and semen was collected and cryopreserved at the end of the feeding trial. Semen was analyzed using CASA and flow cytometry and utilized to produce embryos in vitro. There were no differences in sperm kinematics between High Gain and Control bulls. However, High Gain bulls had a greater proportion of sperm cells with post-thaw acrosome damage compared with Control bulls. Moreover, semen from High Gain bulls tended to have a greater percentage of sperm cells starting to undergo cell death (early necrotic) and approached a statistical tendency for having fewer sperm cells classified as viable after thawing compared with Control bulls (Figure 3)

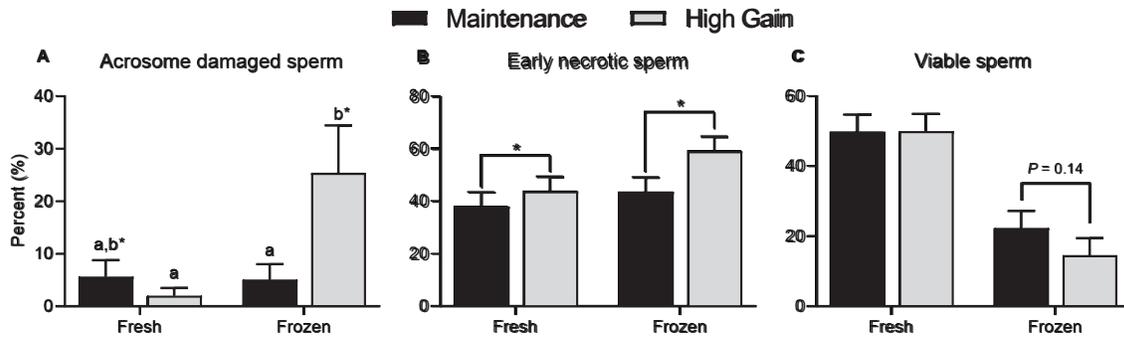


Figure 3 Flow cytometer comparison between bulls fed moderate-gain or high-gain diets prior to cryopreservation and its impacts on acrosome-damaged (a), early necrotic sperm (b), and viable sperm percentage (c). Different superscripts indicate statistical difference ($P < 0.05$), and different symbols indicate a tendency ($P < 0.10$). Source: Seekford et al., 2023.

Although no differences were observed in cleavage rates between High Gain and Control bulls, blastocyst rates relative to the number of oocytes tended to be decreased in High Gain bulls. Moreover, blastocyst rates relative to the number of cleaved oocytes (oocytes that had undergone fertilization) were reduced when semen from High Gain compared with semen from Control bulls (Figure 4). Considering that young bulls are more often exposed to overnutrition compared with mature bulls, our group recently used a similar approach to Seekford et al. (2023) to investigate the impact of overnutrition on the fertility of growing beef bulls. In this trial, 44 half-sibling yearling Angus bulls were developed on either a High Gain (target average gain = 4.0 lbs./day) or a Moderate Gain (target average daily gain = 2.7 lbs./day) diet for 114 days. High Gain treatment resulted in an obese-like metabolic profile characterized by increased insulin resistance and systemic inflammation, associated with subtle decreased semen quality. More specifically, bulls in the High Gain treatment tended to have decreased progressive sperm motility, decreased sperm with intact plasma membrane, and increased sperm with partially damaged acrosome (Fontes et al., 2025). To further assess the impact of these changes on bull fertility, in vitro embryo production was performed using semen from these bulls. Semen from High Gain bulls reduced cleavage and blastocyst rates, reduced the number of trophectoderm cells in the embryos, increased the proportion of apoptotic cells, and resulted in delayed embryonic development (Tariq et al., 2025). Furthermore, Melo-Gonçalves et al. (2025) harvested day 15 filamentous conceptuses generated with semen from the same bulls to evaluate whether paternal nutrition also affects development during conceptus elongation. Transcriptomic analyses were carried out to identify differential gene expression patterns. Preliminary results suggest that semen from High Gain bulls may alter the expression of genes associated with trophectoderm growth and cell proliferation, indicating that sire over-nutrition influences conceptus development past the blastocyst stage. These results indicate that paternal highly anabolic conditions can also induce negative post-fertilization changes in embryo development in cattle.

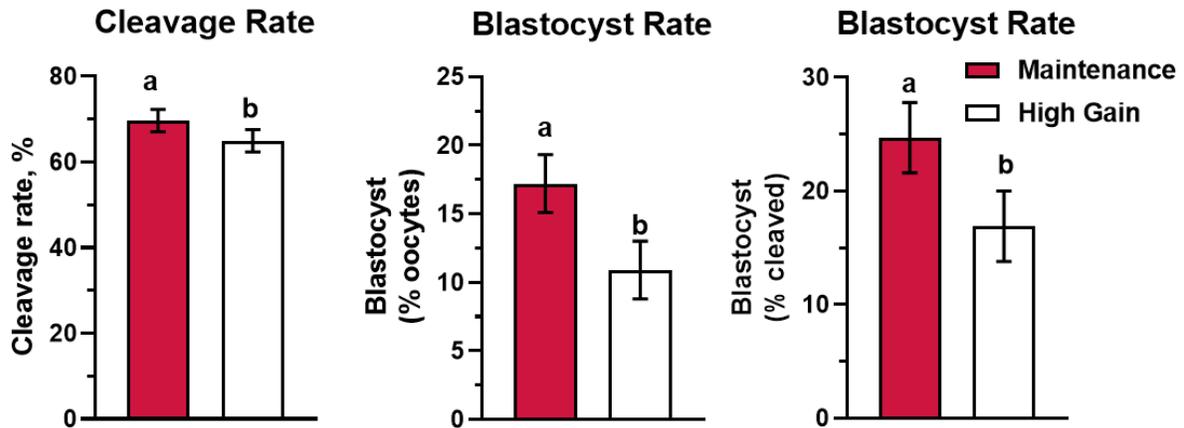


Figure 4 Effect of sire diet on in vitro embryo production. Different superscripts indicate statistical difference ($P < 0.05$) or tendency ($P < 0.10$). Adapted from Seekford et al. (2023).

CONCLUSION

Although sire over conditioning is a common practice in the beef cattle industry, both observational studies and controlled experiments have shown that excessive fat deposition in bulls has detrimental effects on semen quality. Intriguingly, consequences of sire over conditioning to fertility go beyond decreased sperm motility and increased sperm morphology defects. Recent studies indicate that paternal highly anabolic diets also negatively impact postfertilization embryo development. Therefore, while high-energy diets should be utilized to allow young bulls to express the genetic potential for post-weaning growth, producers should be cautious to avoid excessively feeding bulls to an extent that semen quality is compromised.

WORKS CITED

- Barbagallo, F., Condorelli, R.A., Mongioì, L.M., Cannarella, R., Cimino, L., Magagnini, M.C., Crafa, A., La Vignera, S., Calogero, A.E. 2021. Molecular mechanisms underlying the relationship between obesity and male infertility. *Metabolites*. 11:840. doi:10.3390/metabo11120840.
- Cardoso, R.C., Alves, B.R.C., Williams, G.L. 2018. Neuroendocrine signaling pathways and the nutritional control of puberty in heifers. *Anim. Reprod.* 15:868–878. doi:10.21451/1984-3143-AR2018-0013.
- Coulter, G.H., Cook, R.B., Kastelic, J.P. 1997. Effects of dietary energy on scrotal surface temperature, seminal quality, and sperm production in young beef bulls. *J. Anim. Sci.* 75:1048–1052. doi:10.2527/1997.7541048x.
- DeJarnette, J.M. 2005. The effect of semen quality on reproductive efficiency. *Vet. Clin. North Am. Food Anim. Pract.* 21:409–418. doi:10.1016/j.cvfa.2005.02.011.
- DeJarnette, J.M., Harstine, B.R., McDonald, K., Marshall, C.E. 2022. Commercial application of flow cytometry for evaluating bull sperm. *Anim. Reprod. Sci.* 246:106838. doi:10.1016/j.anireprosci.2021.106838.
- Ferrer, M.S., Palomares, R., Hurley, D., Bullington, A., Hoyos-Jaramillo, A., Bittar, J.H. 2020. Antisperm antibodies and sperm function in bulls undergoing scrotal insulation. *Reproduction*. 160:783–792. doi:10.1530/REP-20-0207.
- Fontes, P.L.P., Davis, D.B., Melo-Goncalves, L., Burato, S., Smith, M.S., Stelzleni, A., Fluharty, F.F., Stewart, R.L. Jr., Cooke, R.F., Bromfield, J.J., Else-Keller, A.M., Kerns, K., Strickland, L., Zoca, S.M. 2025. Overnutrition induced metabolic dysregulation and partially decreased semen quality in young beef bulls. *J. Anim. Sci.* (**under review**).
- Franco, G.A., Peres, R.F.G., Martins, C.F.G., Reese, S.T., Vasconcelos, J.L.M., Pohler, K.G. 2018. Sire contribution to pregnancy loss and pregnancy-associated glycoprotein production in Nelore cows. *J. Anim. Sci.* 96:632–640. doi:10.1093/jas/sky015.
- Graham, J.K., Kunza, E., Hammerstedt, R.H. 1990. Analysis of sperm cell viability, acrosomal integrity, and mitochondrial function using flow cytometry. *Biol. Reprod.* 43:55–64. doi:10.1095/biolreprod43.1.55.
- Houfflyn, S., Matthys, C., Soubry, A. 2018. Correction to: Male obesity: epigenetic origin and effects in sperm and offspring. *Curr. Mol. Biol. Rep.* 4:24. doi:10.1007/s40610-017-0084-4.
- Kenny, D.A., Byrne, C.J. 2018. The effect of nutrition on timing of pubertal onset and subsequent fertility in the bull. *Animal*. 12:s36–s44. doi:10.1017/S1751731118000514.
- Koziol, J.H., Armstrong, C.L. 2018. Manual for breeding soundness examination of bulls. 4th ed. Society for Theriogenology, Montgomery, AL.
- Lamb, G.C., Dahlen, C.R., Larson, J.E., Marquezini, G., Stevenson, J.S. 2010. Control of the estrous cycle to improve fertility for fixed-time artificial insemination in beef cattle: a review. *J. Anim. Sci.* 88:2220–2229. doi:10.2527/jas.2009-2349.
- Lamb, G.C., Mercadante, V.R.G. 2016. Synchronization and artificial insemination strategies in beef cattle. *Vet. Clin. North Am. Food Anim. Pract.* 32:335–347. doi:10.1016/j.cvfa.2016.01.006.
- Lucio, A.C., Alves, B.G., Alves, K.A., Martins, M.C., Braga, L.S., Miglio, L., Silva, T.H., Jacomini, J.O., Beletti, M.E. 2016. Selected sperm traits are simultaneously altered after scrotal heat stress and play specific roles in in vitro fertilization and embryonic development. *Theriogenology*. 86:924–933. doi:10.1016/j.theriogenology.2016.03.015.

- McDonald, T.J., Brester, G.W., Bekkerman, A., Paterson, J.A. 2010. Case study: Searching for the ultimate cow: the economic value of residual feed intake at bull sales. *Prof. Anim. Sci.* 26:655–660. doi:10.15232/S1080-7446(15)30663-X.
- Melo-Goncalves, L., Burato, S., Smith, M.S., Tariq, A., Zoca, S.M., Stewart, R.L. Jr., Bromfield, J.J., Fontes, P.L.P. 2025. Impact of sire overnutrition on preimplantation conceptus transcriptome profile in the bovine. *J. Anim. Sci.* (Abstract – in press).
- Mitchell, M., Bakos, H.W., Lane, M. 2011. Paternal diet-induced obesity impairs embryo development and implantation in the mouse. *Fertil. Steril.* 95:1349–1353. doi:10.1016/j.fertnstert.2010.09.038.
- Nevile, W.E., Williams, D.J., Richardson, K.L., Utley, P.R. 1988. Relationship of breeding soundness evaluation score and its components with reproductive performance of beef bulls. *Theriogenology.* 30:429–436. doi:10.1016/0093-691X(88)90191-4.
- Oosthuizen, N., Fontes, P.L.P., Thomas, D., Canal, L.B., Sanford, C.D., DiLorenzo, N., Lamb, G.C. 2018. Relationships among feed efficiency, performance, and value of bulls in the Florida Bull Test. *J. Anim. Sci.* 96(Suppl. 3):200.
- Ortega, M.S., Moraes, J.G.N., Patterson, D.J., Smith, M.F., Behura, S.K., Poock, S., Spencer, T.E. 2018. Influences of sire conception rate on pregnancy establishment in dairy cattle. *Biol. Reprod.* 99:1244–1254. doi:10.1093/biolre/iroy141.
- Reese, S.T., Franco, G.A., Poole, P.K., Hood, R., Fernandez Montero, L., Oliveira Filho, R.V., Cooke, R.F., Pohler, K.G. 2020. Pregnancy loss in beef cattle: A meta-analysis. *Anim. Reprod. Sci.* 212:106251. doi:10.1016/j.anireprosci.2019.106251.
- Rosa, J.L., Freitas, C.P., Missassi, G., Kempinas, W.G. 2023. Multiple flow cytometry analysis for assessing human sperm functional characteristics. *Reprod. Toxicol.* 117:108353. doi:10.1016/j.reprotox.2023.108353.
- Santos, J.E.P., Thatcher, W.W., Chebel, R.C., Cerri, R.L.A., Galvão, K.N. 2004. The effect of embryonic death rates in cattle on the efficacy of estrus synchronization programs. *Anim. Reprod. Sci.* 82–83:513–535. doi:10.1016/j.anireprosci.2004.04.015.
- Seekford, Z.K., Davis, D.B., Dickson, M.J., Goncalves, L.M., Burato, S.B., Holton, M.P., Gordon, J., Pohler, K.G., Lamb, G.C., Pringle, T.D., Stewart, R.L. Jr., Ferrer, M.S., Fontes, P.L.P., Bromfield, J.J. 2023. Bulls fed a high-gain diet decrease blastocyst formation after in vitro fertilization. *Reproduction.* 166:149–159. doi:10.1530/REP-23-0006.
- Smith, M.S., Solano Aguilar, J.O., Nyhuis, G., Ciriaco, F.M., Zoca, S.M., Strickland, L., Stewart, R.L. Jr., Duggin, J.D., Fontes, P.L.P. 2025. Relationship between phenotypic subcutaneous backfat thickness and spermogram outcomes in young beef bulls. *Transl. Anim. Sci.* 9:txaf039. doi:10.1093/tas/txaf039.
- Tariq, A., Melo-Goncalves, L., Maia, T.S., Hoorn, Q.A., Davis, D.B., Zoca, S.M., Stewart, R.L. Jr., Fontes, P.L.P., Bromfield, J.J. 2025. Overnutrition of young bulls delays in vitro embryonic development and decreases embryo quality. *Biol. Reprod.* (**under review**).
- USDA. 2020. Beef 2017, beef cow-calf management practices in the United States, 2017, report 1. USDA–APHIS–VS–CEAH–NAHMS, Fort Collins, CO. #782.0520.
- Vasconcelos, J.L.M., Carvalho, R., Peres, R.F.G., Rodrigues, A., Junior, I., Meneghetti, M., Aono, F., Costa, W., Lopes, C.N., Cooke, R.F., Pohler, K.G. 2017. Reproductive programs for beef cattle: Incorporating management and reproductive techniques for better fertility. *Anim. Reprod.* 14:547–557. doi:10.21451/1984-3143-AR998.
- Wiltbank, M.C., Parish, N.R. 1986. Pregnancy rate in cows and heifers bred to bulls selected for semen quality. *Theriogenology.* 25:779–783. doi:10.1016/0093-691X(86)90093-2.

Yang, Q., Zhao, F., Hu, L., et al. 2016. Effect of paternal overweight or obesity on IVF treatment outcomes and the possible mechanisms involved. *Sci. Rep.* 6:29787. doi:10.1038/srep29787.

Zoca, S.M., Geary, T.W., Zezeski, A.L., Kerns, K.C., Dalton, J.C., Harstine, B.R., Utt, M.D., Cushman, R.A., Walker, J.A., Perry, G.A. 2023. Bull field fertility differences can be estimated with in vitro sperm capacitation and flow cytometry. *Front. Anim. Sci.* 4:1180975. doi:10.3389/fanim.2023.1180975.

Disclaimer: This proceedings was also used at the Beef Reproduction Task Force's Applied Reproductive Strategies for Beef Cattle meeting in North Platte, Nebraska.

LEVERAGING REPRODUCTIVE TECHNOLOGIES

Kacie L. McCarthy, University of Nebraska – Lincoln
Shelby L. Rosasco, University of Wyoming

INTRODUCTION

Reproductive efficiency is a cornerstone of profitability in cow-calf production systems. Technologies such as estrus synchronization, artificial insemination (AI), and pregnancy detection offer producers tools to improve herd fertility, tighten calving seasons and enhance genetic progress. Despite these benefits, adoption of reproductive technologies remains relatively low, particularly in smaller operations. For example, the National Animal Health Monitoring System (NAHMS) reported that AI use among cow-calf operations increased from 6.1% in 1997 to 11.6% in 2017 with larger operations adopting AI at higher rates than small operations (29.4 vs. 8.7%, respectively). However, estrus synchronization was used by only 7.3% of operations in 2017 (Figure 1). Adoption depends on factors such as current reproductive performance, facilities, labor availability, and expected economic return.

Reproductive failure and infertility represent significant economic losses, with previous reports suggesting a loss of \$6.25 per exposed cow for every 1% decrease in pregnancy rates and projected a gross loss of \$2.8 billion annually in the United States due to infertility (Lamb et al., 2014). Cows or heifers that fail to become pregnant during the breeding season are often culled, resulting in increased development or maintenance costs for herd mates, negatively impacting the overall profitability of the operation.

Synchronization, AI, and pregnancy detection may help mitigate some of these losses by increasing pregnancy rates, improving calving distribution, and lifetime productivity. These strategies lead to more calves born earlier in the calving season and greater subsequent weaning weights (Larson et al., 2010). Additionally, heifers that calve earlier have greater herd longevity and produce more

Breeding practices in 2017

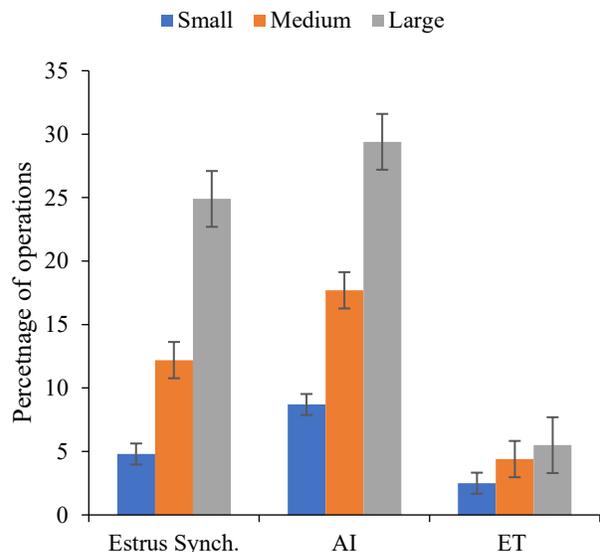


Figure 1. Breeding practices in the United State among small, medium and large operations in 2017. AI: Artificial Insemination; ET: Embryo Transfer. Adapted from NAHMS, 2020

pounds of calf during their lifetime than heifers calving later (Cushman et al, 2013). The purpose of this paper is to highlight practical strategies for integrating reproductive technologies into cow-calf operations, focusing on identifying good candidates, understanding calving distribution, improving reproductive efficiency and overall herd profitability.

IDENTIFYING GOOD CANDIDATES FOR REPRODUCTIVE TECHNOLOGIES

The primary goal of cow-calf production is to efficiently wean a marketable calf from every cow each year, which depends heavily on reproductive efficiency. Selecting appropriate candidates for reproductive technologies is essential for achieving optimal conception rates and improving calving distribution. A well-managed calving distribution ensures that a higher proportion of calves are born early in the season, resulting in uniform weaning weights, improved marketing opportunities and overall herd efficiency.

Evaluating calving distribution, such as the proportion of the herd calved by day 21, 42, and 63 of the calving season, provides insight into reproductive performance and the effectiveness of pre-breeding and breeding management. Ideally, the majority of calves are born early in the calving season, as this reflects good nutritional management, adequate body condition at calving and breeding, and sound herd health management. Calving distribution also helps assess heifer development programs and the management of first-calf heifers. Combined with pregnancy rates after a 60-to-70-day breeding season, these metrics can determine whether animals are good candidates for estrus synchronization and AI. Pregnancy rates of 85% or higher indicate readiness for implementing these technologies, while lower rates suggest underlying management issues that should be addressed first.

Postpartum cows are considered good candidates for estrus synchronization programs when they meet key criteria:

1. A body condition score (BCS) of at least 5 at calving (scale: 1 = emaciated, 9 = obese).
2. The group to be synchronized should have an average postpartum interval of 40 days or more at the start of the protocol. This does not require every cow to be ≥ 40 days postpartum, but the group mean should meet this threshold.
3. If the protocol includes Controlled Internal Drug Release (CIDR) administration, each cow should be at least 21 days postpartum at the time of insertion.
4. A low incidence of calving difficulty, as dystocia can extend the postpartum interval and delay readiness for breeding.

Meeting these benchmarks ensures that synchronization and AI protocols are applied to animals most likely to respond successfully, improving conception rates and tightening calving distribution for greater herd efficiency.

HORMONAL TOOLBOX FOR ESTRUS SYNCHRONIZATION

The bovine estrous cycle is regulated by a series of hormonal changes that control ovarian activity, including follicular development and corpus luteum (CL) formation. This cycle typically recurs every 21 days, with ovulation occurring approximately 24 to 32 hours after the onset of standing estrus. Estrus synchronization simply implies the manipulation of heifers and (or) cows to cause them to exhibit standing estrus (heat) around the same time. This shortens the time required for heat detection and increases breeding efficiency by providing two opportunities for conception within the first month of the breeding season, allowing a greater proportion of females to become pregnant early.

Progestins, including exogenous progesterone and melengestrol acetate (MGA) mimic progesterone produced by the CL to inhibit estrus and ovulation. They are an effective method of synchronizing ovulation in cattle (Odde, 1990) by extending the luteal phase of the estrous cycle. After removal of the progestin, concentrations of progesterone decrease and standing estrus and ovulation will occur. Two progestin products that are commercially available for synchronization include MGA and the CIDR. The CIDR is a T-shaped intravaginal device that delivers a consistent dose of progesterone and is widely used in synchronization protocols to regulate estrus timing. In contrast, MGA is an orally active progestin approved for use in heifers to suppress estrus. MGA is typically fed at 0.5 mg/day per heifer for 14 days, followed by a Prostaglandin F2 α injection 19 days later to synchronize estrus.

Prostaglandin F2 α (PG) regresses the CL and allows heifers and cows to return to estrus. It is effective when administered between days 5 and 17 of the estrous cycle. However, if a cow or heifer does not have a CL (postpartum anestrus cows or prepubertal heifers), they will not respond. Gonadotropin-Releasing Hormone (GnRH) stimulates ovulation or synchronizes follicular waves. In females with large, healthy follicles, GnRH can induce ovulation approximately 24 to 30 hours post-injection, often without visible estrus behavior. It may also initiate cycles in anestrus females nearing cyclicity. For a list of hormones, their biological functions, their role in the estrous cycle and synchronization, and product names see Table 1.

These hormonal protocols are adaptable for use with both natural service and AI, including fixed-time AI (FTAI), heat detection-based AI, and protocols designed for use with sexed semen. Comprehensive protocol guidelines are available through the Beef Reproduction Task Force at <https://beefrepro.org/>, which offers valuable guidance for selecting and implementing synchronization protocols and AI strategies tailored to specific herd goals. Furthermore, proper hormone handling is essential for protocol success. Hormones should be stored according to manufacturer recommendations, and administration should follow Beef Quality Assurance (BQA) guidelines to ensure animal welfare and product efficacy.

Table 1. Reproductive hormones, the endocrine gland from which they originate, their functions during the estrous cycle and role in estrous synchronization. Adapted from Smith et al., 2018.				
Hormone	Endocrine Gland	Function of Hormone	Role in Estrous Sync.	Product Name
Progesterone	Corpus Luteum	Inhibit estrus; inhibit ovulation; prepares animal for pregnancy; maintenance of pregnancy	Inhibit estrus; inhibit ovulation; induce cyclicity; dominant follicle turnover	Melengestrol Acetate (MGA); EAZI-BREED CIDR®
Prostaglandin F2 α	Uterus	Induce luteal regression	Induce premature luteal regression	Lutalyse®; Lutalyse Hi-Con®; Estrumate®; estroPLAN®
Gonadotropin releasing hormone (GnRH)	Hypothalamus	Controls secretion of LH; induces gonadotropin surge	Synchronize follicle wave; induce ovulation	Cystorelin®; Factryl®; Fertagyl®; GONAbreed
Follicle Stimulating Hormone (FSH)	Anterior Pituitary Gland	Initiation of a follicular wave	Superovulation	Follitropin®
Luteinizing Hormone (LH)	Anterior Pituitary Gland	Stimulated by GnRH; induction of ovulation, oocyte maturation; luteal tissue formation	Synchronize follicular wave; induction of ovulation	N/A
Estradiol	Ovarian follicle	Estrous behavior; induction of gonadotropin surge; sperm transport	Dominant follicle turnover; estrous behavior	N/A

OVERVIEW OF REPRODUCTIVE TECHNOLOGIES

Several reproductive technologies are available to beef producers, each offering distinct advantages that can be tailored to specific herd goals, management styles, and resource availability.

Estrus Synchronization: The goal of estrus synchronization is programming the estrous cycle of a group of females so that most of them will come in heat and ovulate within a short time frame. While synchronization is commonly paired with AI, it can also be implemented in natural service programs. Synchronization is achieved through the strategic administration of hormones according to established protocols (Lamb and Mercadante, 2016). Before we consider the impact of

synchronization, we may want to review what we might expect without any intervention. Under normal conditions, cyclic females exhibit estrus randomly across a 21 day cycle, meaning approximately 4.8% of females would be in standing heat on any given day (1 day ÷ 21 days in an estrous cycle). Based on this distribution, about 24% of cyclic females would show estrus within the first 5 days of the breeding season, and roughly 48% within the first 10 days. While females will conceive throughout the breeding season, the average conception date for those bred during the first estrous cycle is around day 10, the midpoint of the cycle (Dahlen, 2013).

Consider the one-shot PG protocol for natural service, approximately 76.2% of cyclic females will exhibit estrus within a 5-day window. Specifically, females that were in days 1 to 5 of their estrous cycle at the start of the breeding season are likely to come into heat between days 17 and 21. This results in an average day of conception at day 6.8 of the estrous cycle (3.2 day advantage compared with no synchronization). Another option for estrus synchronization during natural service is administering an injection of PG 4 or 5 days after bull turnout. This results in females exhibiting estrus over the next 5 days (days 6 to 10 of breeding season). One advantage to this method is that it allows bulls to acclimate to breeding pastures and breed roughly 19-20% of cyclic females before the synchronization protocol is initiated.

In circumstances where synchronization products have been administered to cattle and planning AI date is no longer a possibility (semen not delivered, semen tank is dry, injured technician, etc.) breeding synchronized cows with bulls may be the only way to salvage a bad situation. In these instances, it would be useful to know about the protocols used for synchronizing cows for natural service breeding and note that these protocols can be quite different than those used to synchronize females for AI. Those protocols can be reviewed here <https://beefrepro.org/natural-service-protocols/> for future reference.

Heat detection: Successful insemination requires accurate detection of standing estrus, which refers to observing behavioral changes indicating a cow or heifer is receptive to mounting by another animal. To improve detection efficiency, producers can use commercially available aids such as Estroject patches alongside visual observation. Other common tools include tail chalk/paint, pressure mount detectors, gomer bulls (teaser bulls: rendered sterile by vasectomy, epididymectomy, and (or) penile deviation), and androgenized cows. Table 2 provides an overview of these aids, including how they work, potential concerns and relative costs. Additionally, there are specific heat detection protocols (<https://beefrepro.org/heat-detection-protocols/>) that can be utilized for either cows or heifers.

Table 2. List of estrus detection aids in beef cattle with a description of how they work, potential concerns, and relative cost. Adapted from Smith et al., 2018			
Heat Detection Aid	How it Works	Potential Concerns	Relative Cost
Tail Chalk	Chalk is applied to tailhead. When animal is mounted the color will be rubbed off and hair will be ruffed.	Removal by trees, water, fences, or licking by other animals.	\$
Heat Mount Detectors	Detectors are applied to tailhead and turn a different color when mounted.	Partial activation or loss of detector requires interpretation, false activation (i.e. trees, fences, other animals)	\$\$
Heat Watch	Transmitters are attached to tailhead region. When transmitter is depressed, a signal is sent to receiver.	Expensive to replace lost sensors, data interpretation, appropriate facilities/terrain.	\$\$\$
Gomer Bulls	Vasectomized, epididymectomized, and (or) penile-deviated animals are used as a teaser animal and will mount females in estrus.	Feeding and maintenance expense, potential loss of desire to mate, and disease transmission by non-penile-deviated animals.	\$\$\$
Chin Ball Marking Harness	Detector animal is fitted with harness leaving an inkmark on the back and neck of females that have been mounted.	Maintenance of equipment, feeding and maintenance of animal, ill-defined markings.	\$\$
Androgenized cows	Testosterone injections before and during the breeding season or androgen implant causes cow to mount other females in heat.	Cost and labor of administering drug, variable response to hormone.	\$\$

Artificial Insemination (AI): Enables producers to access superior genetics from proven sires without the financial burden of purchasing and maintaining high value bulls. This technology accelerates genetic progress in traits such as growth rate, carcass quality, fertility, and calving ease while also promoting more uniform calf crops. Despite these advantages, AI adoption remains low among U.S. cow-calf operations. According to the 2017 NAHMS survey, only 11.6% of operations reported using AI, with larger operations adopting at higher rates than smaller ones (NAHMS, 2020).

Additional resources for selecting and implementing estrus synchronization protocols, as well as information about AI and reproductive management of beef cattle can be found on the Beef Reproduction Task Force website (<https://beefrepro.org/>).

Heat detection and Timed AI (TAI): Heat detection combined with TAI involves monitoring females for signs of estrus over a 3-day period, with insemination occurring 6 to 12 hours after observed estrus. Females that do not exhibit estrus during this time (nonresponders) are then inseminated during timed AI 72 to 84 hours after PG with GnRH given at the time of insemination. This reduces the labor and amount of time required for heat detection while giving early responders a better chance of conceiving compared to a single fixed-time AI.

Fixed-time AI (FTAI): A specialized form of AI, FTAI involves synchronizing estrus so that all cows in a group can be inseminated at a fixed time, eliminating the need for estrus detection. For cows, FTAI can produce pregnancy rates similar to those of protocols that require 5 to 7 days of heat detection. For heifers, pregnancy rates from current TAI protocols tend to be 5 to 10 percent lower than using heat detection alone. The scheduled insemination times for FTAI represent average expected times and it is recommended to synchronize only as many females as can be inseminated within a 3-to-4-hour window at a given facility to ensure optimal results.

Estrus synchronization with AI can be an effective management tool to produce replacements that are older at breeding, become pregnant early in the breeding season, and have the potential to provide superior genetics. Previous research has shown females that conceived to AI as a yearling also had greater average weaning weights for calves produced during their lifetime and weaned more weight and more total calves than females conceived to natural service (French et al., 2013). Furthermore, conceiving to AI rather than to a clean-up bull via natural service as a yearling allowed females to wean an additional 699 pounds and 2 calves over their productive lives (French et al., 2013).

Moreover, Steichen et al. (2013) conducted a study in North Dakota comparing natural service and artificial insemination breeding systems in beef cattle and found that AI-bred calves born in the first 21 days of the calving season were 19.4 pounds heavier at weaning than those born to natural service during the first 21 days. Producers should compare the cost of natural service alone with one round of AI followed with bulls to breed cows that did not conceive during insemination. The important value here is the cost per pregnancy. Breeding costs are dependent on bull-to-cow ratio, cost of bulls, cost of AI, herd size and the expected pregnancy rate from AI.

Sexed Semen: Allows producers to predetermine the sex of offspring, enabling targeted production of replacement heifers or terminal male calves. Though conception rates may be slightly lower than conventional semen, the ability to manage herd demographics more precisely offers long-term economic benefits. Sexed semen can be used on any female observed in heat and following synchronization with any protocol on the sheet: https://beefrepro.org/wp-content/uploads/2024/12/BRTF_Protocol-sheets-2025_FINAL_Sexed-Semen.pdf. For best results, it is recommended to perform AI 16 to 22 hours after detecting females in estrus and use of estrus detection aides are highly recommended.

Embryo Transfer (ET): Embryo transfer propagates elite genetics by transferring embryos from high-value donor cows into recipient females. This accelerates genetic progress by producing multiple offspring from superior females in a single season. Embryo transfer is especially valuable in seedstock operations or herds focused on rapid genetic advancement. Additional information on

the procedures and considerations can be found here: <https://extension.msstate.edu/publications/embryo-transfer-the-beef-herd>.

Pregnancy detection methods: There are different methods available when it comes to pregnancy diagnosis and it is important for producers to know what options are available and allow them to decide on the most economically viable strategy to diagnose pregnancy on their operation. Another component to selecting a detection method is also developing the veterinarian-client-patient-relationship with local veterinarians. This can help producers evaluate the different alternatives available and determine which method works best for their operation.

Utilizing pregnancy detection early can be an important management tool that enables producers to make timely decisions about culling, rebreeding or marketing females. Pregnancy detection can be performed by rectal palpation, transrectal ultrasonography, or blood test. Palpation and transrectal ultrasonography are conducted by a specialized technician. Rectal palpation and ultrasonography provide “real-time” results, and the female is referred to as either “pregnant” or “open” (not pregnant). Starting 30 days after the expected date of conception, pregnancy tests can exhibit high accuracy (Pohler et al., 2020). Ultrasound offers the added advantage of fetal aging, which helps group cows by expected calving dates for better nutritional management and reduced calf health risks. Furthermore, operations who utilize AI followed by bull breeding can conduct two pregnancy tests to 1) measure conception to AI and 2) overall reproductive performance of the operation. For blood tests, a sample is collected by the operation and usually shipped to a laboratory that will perform the test and send results back to the producer. While blood tests provide early detection (28 to 32 days), results take 5 to 7 days and do not allow for immediate sorting or staging. Blood testing may also lead to false positives; meaning cows who conceived, and subsequently resorbed pregnancies may still have levels of circulating hormone that result in a positive test. It is important to note that cows and (or) heifers need to be at least 73 days post calving. This will help prevent a false positive result due to any residual Pregnancy Specific Protein B that has not cleared the maternal system from cows that calved less than 73 days ago. Using these tools early in the breeding season may help producers conserve forage, improve calving distribution, and make informed decisions based on reproductive status.

BENEFITS OF REPRODUCTIVE TECHNOLOGIES

Optimizing the number of cows and heifers that conceive early in the breeding season improves reproductive efficiency, calving distribution, and longevity. Cows that conceive late in the breeding season will calve late in the calving season and wean calves that are younger and lighter compared to cows that conceive and calve early. Research has indicated that animals that calve late in the calving season have an increased chance of calving late or not calving the next year (Burriss and Priode, 1958). In contrast, heifers born in the first 21 days of the calving season had increased body weight at weaning, pre-breeding, and pregnancy diagnosis, as well as a greater percentage of heifers cycling at the beginning of the breeding season and increased pregnancy rates compared to heifers born later in the calving season (Funston et al, 2012). Moreover, Funston et al. (2012) reported steers born during the first 21 days of the calving season had increased weaning weights, increased hot carcass weights, greater marbling scores, and an increase in carcass value compared to steers born later in the calving period. Therefore, increasing the number of calves born early in

the calving season can result in heavier calves at weaning, improved carcass characteristics, and increased reproductive performance of heifers.

Previous research has indicated that heifers calving in the first 21-day period of their first calving season have increased calf weaning weights through the first 6 calves compared to their contemporaries calving later in their first calving season (Cushman et al., 2013). Heifers calving early in their first calving season wean more pounds of calf over their lifetime, which amounts to the production of an extra calf during their lifetime (Cushman et al., 2013). This represents a significant financial advantage for the operation. Furthermore, heifers calving in the first 21-day period of their first calving season remained in the herd longer compared to heifers calving for the first time in the second or third 21 days of the calving season (Cushman et al., 2013). The development and utilization of management strategies that focus on heifers conceiving early in their first breeding season can help increase the survivability and lifetime productivity of heifers. Producers that can afford to develop extra heifers could have the option to place additional selection pressure for heifers that conceive early in the breeding season. Breeding extra heifers would provide the opportunity to select replacement heifers that conceived early in the breeding season by estimating fetal age at pregnancy diagnosis. A similar strategy would be to develop additional heifers and utilize a shorter breeding season (approx. 30 days) and make selection decisions from pregnant heifers at pregnancy diagnosis. Open heifers would still be in the age range to be marketed in the feeder cattle market. Lastly, utilization of estrus synchronization can allow more females to be bred earlier in the breeding season, as well as hasten the onset of puberty attainment and shorten the PPI in late-calving females (when using a progestin-based protocol), allowing them to conceive earlier in the breeding season.

Maintaining a defined breeding season and even decreasing the length of the breeding season can increase efficiency within the herd. A defined breeding season will allow for a shortened calving season, providing cows and heifers time to return to estrus cyclicity prior to the breeding season, allow concentration of labor during the calving season, increase uniformity of the calf crop, and allow for more efficient nutritional and health management. An extended calving season can result in periods of over- or under-nutrition for different groups of cows depending on the stage of production (gestation or lactation) the diet is balanced to meet. Overall, increasing the number of females calving early through synchronization and AI improves calf performance, carcass quality, and reproductive success, driving profitability in cow-calf operations.

CONCLUSION

Integrating reproductive technologies strategically can improve herd fertility, productivity, and profitability. Success depends on proper candidate selection, protocol adherence, and management practices. As technologies evolve and become more accessible, even small and medium-sized operations can benefit from adopting these tools to enhance performance and long-term profitability.

REFERENCES

Burris, M. J., and B. M. Priode. 1958. Effect of calving date on subsequent calving performance. *J. Anim. Sci.* 17:527-533. doi.org/10.2527/jas1958.173527x

- Cushman, R. A., L. K. Kill, R. N. Funston, E. M. Mousel, and G. A. Perry. 2013. Heifer calving date positively influences calf weaning weights through six parturitions. *J Anim Sci.* 91(9):4486-4491.
- Dahlen, C.R. 2013. Control of estrus with natural service. *Applied Reproductive Strategies in Beef Cattle Symposium.* <https://beefrepro.org/wp-content/uploads/2020/09/10-carl-dahlen.pdf>
- French, J.T., J.K. Ahola, J.C. Whittier, W.M. Frasier, R.M. Enns, R.K. Peel. 2013. Differences in lifetime productivity of beef heifers that conceived to first-service artificial insemination (AI) or a clean-up bull via natural service (NS) as a yearling and among females that were offspring of an AI or NS mating. *Prof. Anim. Sci.* 29: 57-63. [https://doi.org/10.15232/S1080-7446\(15\)30196-0](https://doi.org/10.15232/S1080-7446(15)30196-0).
- Funston, R. N., and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. *J. Anim. Sci.* 82:3094-3099.
- Funston, R.N., J.A. Musgrave, T.L. Meyer, and D.M. Larson. 2012. Effect of calving distribution on beef cattle progeny performance. *J. Anim. Sci.* 90:5118-5121.
- Lamb, G. C., C. Dahlen, V. R. G. Mercadante, and K. Bischoff. 2014. What is the impact of infertility in beef cattle? *EDIS Submissions. Inst. Food Agric. Sci. Univ. Florida.*
- Lamb, G. C., and V. R. Mercadante. 2016. Synchronization and Artificial Insemination Strategies in Beef Cattle. *Vet. Clin. North Am. Food Anim. Pract.* 32(2): 335–47. doi: 10.1016/j.cvfa.2016.01.006.
- NAHMS. 2020. Beef 2017: Beef Cow-Calf Management Practices in the United States, 2017. Accessed on November 1, 2025. https://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/beef2017/Beef2017_dr_PartI.pdf
- Odde, K. G. 1990. A review of synchronization of estrus in postpartum cattle. *J. Anim. Sci.* 68(3):817-830. doi: 10.2527/1990.683817x
- Pohler, K. G., S. T. Reese, G. A. Franco, R. V. Oliveira, R. Paiva, L. Fernandez, G. de Melo, J. L. M. Vasconcelos, R. Cooke, and R. K. Poole. 2020. New Approaches to Diagnose and Target Reproductive Failure in Cattle. *Anim. Reprod.* 17(3):e20200057. doi:10.1590/1984-3143-AR2020-0057
- Smith, M.F., G.A. Perry, K.G. Pohler, M.K. McLean, L.A. Ciernia, and D.J. Patterson. 2018. Establishment of pregnancy in beef cattle: application of basic principles. *Applied Reproductive Strategies in Beef Cattle Symposium.* <https://beefrepro.org/wp-content/uploads/2020/09/SMITH-Basic-Principles-2018.pdf>
- Steichen, P.L., S.I. Klein, Q.P. Larson, K.M. Bischoff, V.R.G. Mercandante, G.C. Lamb, C.S. Schauer, B.W. Neville, and C.R. Dahlen. 2013. “Effects of Natural Service and Artificial Insemination Breeding Systems on Calving Characteristics and Weaning Weights.” *North Dakota Beef Report.* Online: [effects-of-natural-service-and-artificial-insemination-breeding-systems-on-calving-characteristics-and-weaning-weights](https://www.ndbeefreport.com/effects-of-natural-service-and-artificial-insemination-breeding-systems-on-calving-characteristics-and-weaning-weights)

CARBON CREDIT MARKETS

Nicole (Nicki) Nimlos
Department of Ecosystem Science & Management
College of Agriculture, Life Sciences, and Natural Resources
University of Wyoming

INTRODUCTION

Voluntary carbon markets present an emerging opportunity for agricultural producers to generate additional income by improving their management activities. Unlike regulatory or “cap-and-trade” markets, where companies are required to stay below a set emissions threshold, voluntary markets allow companies to purchase carbon credits to offset their emissions and demonstrate environmental responsibility to consumers. Producers can generate carbon credits by adopting management practices that aim to increase soil carbon sequestration, the process by which plants capture atmospheric carbon dioxide (CO₂) through photosynthesis and store it in the soil. One carbon credit equals one metric ton of CO₂ equivalents sequestered in the soil or prevented from being released through activities such as tillage. Examples of management practices that have the potential to increase soil carbon sequestration include short-duration, high-intensity grazing with extended rest periods, cover cropping, reseeding native perennials, and reducing tilling. While more than 170 different types of carbon credits exist globally (Ecosystem Marketplace, 2022), this paper focuses specifically on credits generated from rangeland systems within the agricultural sector.

Research regarding the long-term impacts of grazing management on soil carbon sequestration in western rangelands remains limited. Some studies suggest that transitioning from continuous grazing to adaptive multi-paddock grazing can increase soil carbon sequestration (Kim et al., 2023; Mosier et al., 2021), while others have found no significant differences among grazing strategies (Gergeni et al., 2023) or even reported negative impacts of grazing on soil carbon (Golluscio et al., 2009). However, in semiarid rangelands, factors such as climate and soil texture are major determinants of soil carbon stocks and may override the effects of management practices (Sanderson et al., 2020). These environmental constraints must therefore be considered when evaluating the potential profitability and feasibility of carbon projects in rangeland systems.

CARBON MARKET OVERVIEW

To join the carbon market, producers typically collaborate with a project developer, also known as a carbon company (Figure 1). This partnership begins with the creation of a carbon project plan and the signing of a contract that outlines the producer’s responsibilities and the project requirements. Project developers ensure that carbon projects comply with the standards established by the registries, who are the governing bodies that create and maintain the methodologies required for generating carbon credits. Common registries include American Carbon Registry

(<https://acrcarbon.org>), Climate Action Reserve (<https://climateactionreserve.org>), Nature's Registry (<https://www.aeinsteinstitute.org/natures-registry>), and Verra (<https://verra.org>). These registries maintain publicly accessible databases that track all registered carbon projects.

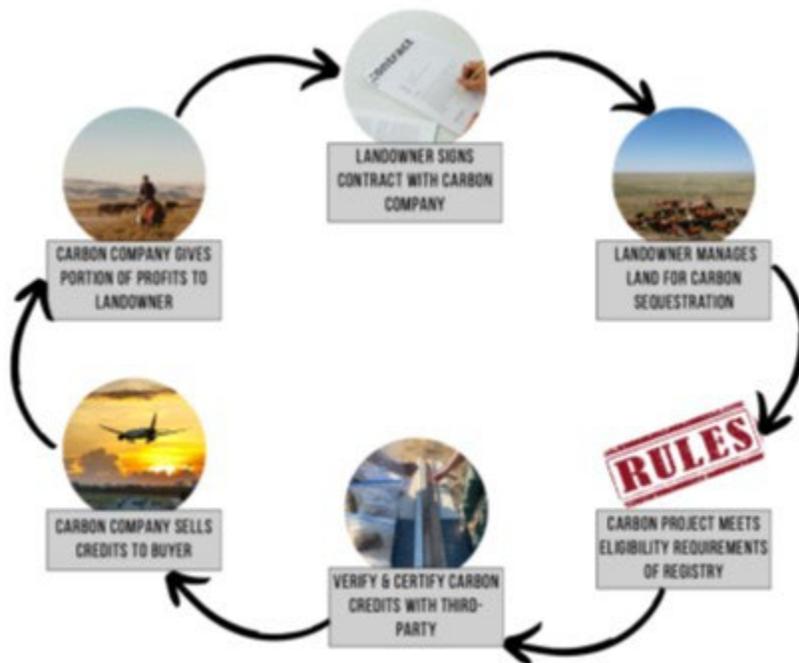


Figure 1. Overview of how the carbon market functions.

The project developer should cover all administrative and operational costs associated with joining the carbon market, including registration, verification, and expenses related to implementing new management practices. Producers are typically provided with up-front payments to support the implementation of the management changes, such as pasture subdivision (via physical, temporary, or virtual fencing), water development, seed purchase, or fertilizer application. It is essential that producers avoid investing their own funds in these initial steps, and project developers should assume all upfront financial risk. The project developer is also responsible for ensuring that the carbon project becomes verified and certified by an independent third-party, who determines the number of carbon credits issued to the project based on soil sampling or model estimates.

To determine the number of carbon credits a project can generate, a baseline must first be established. This baseline represents the condition of the land prior to any management changes and serves as the reference point for measuring additional carbon accumulation over time. Once the baseline is established, the producer is then responsible for implementing the agreed-upon management practices as outlined in the contract. Every three to five years, the third-party verifier returns to the site and re-estimates soil organic carbon. The difference between the new measurement and the baseline determines the number of carbon credits to be issued. For example, if the baseline contained 30 metric tons of soil organic carbon per acre and five years later held 35 metric tons, the project would generate five carbon credits per acre. After issuance, the registry records and tracks the credits until they are sold and officially “retired” upon purchase. Project

developers typically have relationships with buyers to facilitate the sale of credits once they become available.

Despite the variety of entities involved in the carbon market, they follow a similar set of core requirements. Primarily, the producer must provide evidence of additionality, meaning that the observed soil carbon gains would not have occurred without the financial incentives of the carbon project or that the land would have otherwise been converted to cropland or developed (Nimlos et al., 2025). Put simply, producers must adopt a new practice beyond their current management, such as increasing the frequency of livestock movement, extending rest periods between grazing, planting cover crops or interseeding, or placing land under a conservation easement to prevent tillage or development. In the case of conservation easements (also referred to as “Avoided Conversion of Grasslands”), the property must be located in an area where the risk of conversion to crop production or development is high.

Project developers do vary in the specific terms of their contracts, including contract length (ranges from 10-100 years), required management changes, payment amount and timing, and minimum acreage required for enrollment. These variations depend on the methodology and registry under which a carbon project is developed. For example, American Carbon Registry’s *Avoided Conversion of Grasslands and Shrublands to Croplands* methodology requires that participating lands be placed under a conservation easement to prevent soil carbon losses from tillage. In contrast, Verra’s *VM0042 Improved Agricultural Land Management* methodology focuses on improving land management practices such as grazing, fertilizer use, cover crop planting and harvesting methods.

RISKS AND UNCERTAINTY

There are considerable risks producers should be aware of before entering into a carbon contract. One of the most significant is the obligation to repay the project developer for any avoidable reversals, or losses of soil organic carbon that occur due to management actions or negligence. Examples include tilling under a no-till agreement, overgrazing, or violating other terms outlined in the contract. In contrast, unavoidable reversals, such as soil carbon losses caused from natural disasters including drought, wildfire, or pests, are typically not the producer’s financial responsibility. As long as the producer adheres to the contract stipulations and maintains agreed-upon management practices, they should not face penalties.

Considering there is high uncertainty associated with substantial soil organic carbon accumulation on heterogenous western rangelands (Stanley et al., 2023) and the limited number of active carbon projects, there remains considerable uncertainty surrounding the potential income that producers can generate through carbon markets. Some project developers may choose to cancel a carbon project at no cost to the producer without requiring return of any pre-payments if the project does not appear financially viable long-term. However, this poses a significant risk for producers who may invest substantial time, resources, and effort into implementing new management practices without receiving financial returns.

Producers may also face challenges if they choose to sell their property enrolled in a carbon project due to the long contract lengths. If the buyer is willing to continue participation, the contract can

be transferred to them, allowing the new landowner to receive future revenue without penalty to the original producer. However, if the buyer declines to continue the carbon project, the contract may be terminated, potentially resulting in a breach. The original landowner could be required to repay any pre-payments or cover losses associated with the project's cancellation.

MARKET OVERVIEW

Notably, the agricultural sector was the only sector to experience an increase in carbon credit prices from 2023 to 2024, and companies are purchasing these credits faster than project developers can issue them (Ecosystem Marketplace, 2025). The top buyers of carbon credits in 2024 included Shell, Microsoft, Eni, Primax Columbia, and Canada Growth Fund (Gabbatiss, 2023), with Shell retiring nearly three times as many credits as the next largest buyer, Microsoft. Media coverage, corporate climate targets, and government policies were identified as the most influential external factors driving credits sales (Ecosystem Marketplace, 2025). The average price of carbon credits in the agricultural sector reported in 2024 was \$7.66 per credit. However, some contracts have reported prices as high as \$16-\$20 per credit.

CASE STUDIES

Rotation grazing carbon project

One of the first livestock-related carbon projects was established in 2019 and aggregated four ranches into a single project. The project developer Native implemented the project under Verra's *VM0026 Methodology for Sustainable Grassland Management*, enrolling a total of 33,292 acres (13,473 hectares). After establishing baseline soil organic carbon levels, the landowners were responsible for improving their grazing management. They increased the number of pastures from 23 to 63, reduced the average pasture size from 322 acres (130 hectares) to 118 acres (48 hectares), and decreased the average days grazed per pasture from 39 to 3.5. In 2023 following re-verification in the fifth year, the project was issued 56,508 carbon credits. Assuming a price of \$16 per credit based on other contracts, the estimated total revenue over the five year timespan is:

$$56,508 \text{ carbon credits} \times \$16 \text{ per credit} = \$904,128$$

Dividing by five years gives an estimated annual revenue of:

$$\frac{\$904,128}{5 \text{ years}} = \$180,825.60 \text{ per year}$$

On a per acre basis, this equates to:

$$\frac{\$180,825.60 \text{ per year}}{33,292 \text{ acres}} = \$5.43 \text{ per acre per year} \text{ [\$13.42 per hectare per year]}$$

It is important to note that these are rough estimates. Actual revenue is likely lower because project developers typically deduct initial project setup costs and improved management implementation expenses and will share a portion of the profit with producers.

Crop production carbon project

The project developer Carbon Friendly initiated an aggregated carbon project with six farmers in the central valley of California under Verra's *VM0042 Improved Agricultural Land Management* methodology. At the time of validation, the project encompassed 5,000 acres (2,023 hectares) of orchards and vineyards with a baseline scenario of conventional crop management practices without crop rotation. Participating producers implemented management changes that included multi-species cover cropping and the application of organic amendments such as compost, mulch, and manure. The project is currently under validation and has not yet received carbon credits, as the five-year resampling and verification period has not been completed.

Avoided conversion of grassland through a conservation easement

In consultation with the project developer Kateri, a southeastern Wyoming producer explored enrollment in American Carbon Registry's *Avoided Conversion of Grasslands and Shrublands to Crop Production* methodology. This methodology requires landowners to place eligible land under a conservation easement containing a no-till clause. To qualify, it must be demonstrated that the baseline land-use scenario in the region is crop production, indicating that without the easement, grassland or shrubland conversion to cropland would likely occur. Of the landowner's approximately 4,000 acres (1,619 hectares), about 600 acres (243 hectares) were deemed to be at risk of conversion and therefore eligible for enrollment. Kateri estimated that these 600 acres could generate roughly 450 carbon credits per year and offered the producer \$25,000 upfront for the easement plus \$2,000 annually for the 30-year duration of the carbon project.

CONCLUSION

Carbon markets can provide a financial opportunity for producers looking to improve their management practices while being compensated for their land stewardship. For landowners interested in placing their land under a conservation easement, carbon projects can align well with long-term conservation goals. However, participation in carbon markets requires careful consideration. Factors such as contract length, required management changes, and potential financial risk and uncertainty vary widely across programs. Given the long-term commitments and legal complexities of carbon contracts, producers are strongly encouraged to consult with a lawyer before signing any agreement. Because agricultural carbon markets are still relatively new, there may be flexibility to negotiate terms that better align with an individual operation. Producers are advised to explore multiple companies and compare contract terms to ensure the best fit for their management goals and financial objectives.

REFERENCES

Ecosystem Marketplace. (2022). The art of integrity. State of the voluntary carbon markets 2022 Q3. Washington DC: Forest Trends Association.
<https://www.ecosystemmarketplace.com/publications/state-of-the-voluntary-carbon-markets-2022/>

- Ecosystem Marketplace. (2025). State of the voluntary carbon market 2025: Meeting the moment renewing trust in carbon finance. Washington DC: Forest Trends Association.
<https://www.ecosystemmarketplace.com/publications/2025-state-of-the-voluntary-carbon-market-sovcm/>
- Gabbatiss, J. (2023). Analysis: How some of the world's largest companies rely on carbon offsets to 'reach net-zero.' Carbon Brief. <https://interactive.carbonbrief.org/carbon-offsets-2023/companies.html>
- Gergeni, T., Scasta, J. D., Maczko, K., Paisley, S., & Tanaka, J. (2023). Temporal variability drives soil chemical and biological dynamics more than grazing in a northern mixed-grass prairie. *Plant, Soil and Environment*, 69(7), 344–362. <https://doi.org/10.17221/54/2023-PSE>
- Golluscio, R. A., Austin, A. T., García Martínez, G. C., Gonzalez-Polo, M., Sala, O. E., & Jackson, R. B. (2009). Sheep grazing decreases organic carbon and nitrogen pools in the Patagonian steppe: Combination of direct and indirect effects. *Ecosystems*, 12(4), 686–697. <https://doi.org/10.1007/s10021-009-9252-6>
- Kim, J., Ale, S., Kreuter, U., Teague, W., DelGrosso, S., & Dowhower, S. (2023). Evaluating the impacts of alternative grazing management practices on soil carbon sequestration and soil health indicators. *Agriculture, Ecosystems & Environment*, 342, 108234. <https://doi.org/10.1016/j.agee.2022.108234>
- Mosier, S., Apfelbaum, S., Byck, P., Calderon, F., Teague, R., Thompson, R., & Cotrufo, M. (2021). Adaptive multi-paddock grazing enhances soil carbon and nitrogen stocks and stabilization through mineral association in southeastern U.S. grazing lands. *Journal of Environmental Management*, 288, 112409. <https://doi.org/10.1016/j.jenvman.2021.112409>
- Nimlos, N., Gergeni, T., Scasta, J. (2025). Rancher opportunities in grazing land carbon markets in the United States. *Rangelands*, 47(3), 172-180. <https://doi.org/10.1016/j.rala.2025.01.002>
- Sanderson, J., Beutler, C., Brown, J., Burke, I., Chapman, T., Conant, R., Derner, J., Easter, M., Fuhlendorf, S., Grissom, G., Herrick, J., Liptzin, D., Morgan, J., Murph, R., Pague, C., Rangwala, I., Ray, D., Rondeau, R., Schulz, T., & Sullivan, T. (2020). Cattle, conservation, and carbon in the western Great Plains. *Journal of Soil and Water Conservation*, 75(1), 5A-12A. <https://doi.org/10.2489/jswc.75.1.5A>
- Stanley, P., Spertus, J., Chiartas, J., Stark, P., & Bowles, T. (2023). Valid inferences about soil carbon in heterogeneous landscapes. *Geoderma*, 430, 116323. <https://doi.org/10.1016/j.geoderma.2022.116323>

IMPACTS OF LATE GESTATIONAL UNDERNUTRITION IN BEEF HEIFERS ON DAM AND OFFSPRING OUTCOMES

Colby A. Redifer and Allison M. Meyer
Division of Animal Sciences
University of Missouri

INTRODUCTION

Nutrient requirements increase dramatically in the late gestation beef female to allow for proper growth and function of the uteroplacenta, fetus, and mammary gland. Even in well-managed herds, it is possible for cows and heifers to be nutrient restricted during this time due to challenges of low forage quality or availability and environmental stress brought on by cold (spring-calving) or heat (fall-calving). For heifers, the added nutrient requirements of growth and establishment of a functional uterus and mammary gland for the first time pose an even greater challenge during their first pregnancy.

A growing body of research demonstrates that nutrient restriction during pregnancy can have long-lasting effects on calves resulting from impaired development before and after birth. This is not surprising, as calves depend on their dams for all nutrients before birth, and the majority of nutrients pre-weaning. Late gestational nutrient restriction research generally associates decreased nutrient delivery during gestation with programming fetal growth and development, resulting in poor postnatal outcomes. However, the effects gestational nutrient partitioning may have on programming the mammary gland to decrease milk yield and therefore postnatal nutrient delivery is far less understood. It is also generally unknown how poor nutrition during one pregnancy impacts cows during their next pregnancy and lactation.

EXPERIMENTAL MODEL

To determine the effects of late gestational nutrient restriction in first-parity females, fall-calving Hereford × Simmental-Angus heifers bred to a single sire were used in this study. Heifers were allocated by fetal sex and expected calving date to receive either 100% (control; n = 12) or 70% (nutrient restricted; n = 13) of metabolizable energy and metabolizable protein requirements for maintenance, pregnancy, and growth from day 160 of gestation to calving. Heifers were individually-fed using Calan gates, which allowed animals to eat individual diets while group-housed in pens. Diets were based on low-quality chopped sorghum sudan hay (1.74 Mcal ME/kg, 6.69% CP, 72.0% NDF) from day 160 to 265 of gestation and chopped tall fescue hay (1.90 Mcal ME/kg, 7.22% CP, 65.1% NDF) for the remainder of gestation and lactation. Based on expected individual hay intakes, heifers were supplemented daily with whole corn, dried distillers grains, and soyhull pellets to meet targeted nutritional planes.

After calving, treatments were terminated and all cows were fed to meet energy and protein requirements for maintenance, lactation, and growth. Females continued to be fed individually in Calan gates to ensure individual nutrient intakes remained similar and to prevent calves from having access to feed other than milk. At 5 months post-calving, cow-calf pairs were co-mingled and group-fed hay and supplement until calves were weaned at 8 months of age. Post-weaning, calves were backgrounded in drylots for 2 months and then placed into the feedlot for finishing. Cattle were slaughtered at a similar number of days on feed.

OUTCOMES

Major findings of late gestational nutrient restriction on dam and offspring outcomes are shown in Figure 1. Nutrient restricted females lost body weight and condition and had less nutrients in maternal circulation during late pregnancy. Post-calving, nutrient restricted dams weighed 64 kg less and were 2.0 lower body condition score. Nutrient restricted dams had lower maternal heart rates during pregnancy and less contralateral placental growth (uterine horn opposite of the fetus and CL), yet total uterine blood flow and placental weight were maintained and ensured calf birth weights similar to control dams. Fetal presentation at calving was normal for all control births, while 23.1% (3 of 13) of nutrient restricted dams had calf malpresentations.

Nutrient restricted (NR) heifers	Calves born to NR heifers
↓ Body weight at calving	▬ Birth weight
↓ Body condition score at calving & weaning	▬ Gestation length
↓ Heart rate during pregnancy	≠ Altered placental development
▬ Uterine blood flow	↓ Calf vigor
↓ Circulating nutrients during pregnancy	↑ Stress at birth
↑ Abnormal presentation at birth	▬ Achieved passive transfer of immunity
↓ Colostrum production	↓ Pre-weaning growth
↓ Milk production	▬ Carcass weight and quality grade
↓ Mammary blood flow	↓ Yield grade (numerically lower)

Figure 1. Effects of late gestational nutrient restriction on dam and offspring outcomes in the first parity

It should be noted that when we conducted a similar study using the same experimental model the following year, calf birth weight was reduced by 15% and placental weight by 17%, but uterine blood flow remained unaffected. In combination, these results demonstrated that late gestational nutrient restriction is inconsistent in reducing fetal growth, which appears to be driven more by placental size than uterine blood flow.

While calf birth weight and gestation length were unaffected in this study, nutrient restricted dams had less vigorous calves that were slower to stand and 40% less colostrum yield. Colostrum of nutrient restricted females was more concentrated with IgG, and calf 48-h serum IgG indicated that calves of both treatments had successful passive transfer of immunity. Colostrum of nutrient restricted females had less total lactose, but similar total protein and fat compared with control females. There was no neonatal calf death loss due to treatment; however, this was likely because females were monitored continuously during the calving season for research purposes.

Even when females were fed to meet their energy and protein requirements during lactation, late gestational nutrient restriction reduced milk yield by 15% and decreased milk protein concentration during the first 150 days of lactation. Lower milk production was partially explained by a 19% reduction in blood flow supplying the mammary gland during this time.

By day 21 of lactation, metabolic status of previously nutrient restricted dams had returned to concentrations similar to control dams. During lactation, previously nutrient restricted females gained maternal weight faster and increased body condition. Still, previously nutrient restricted dams had not fully recovered by weaning, as they weighed 17 kg less and were 0.7 lower body condition score. Females in both treatments were similarly successful in rebreeding for a 2nd calf and comparable to industry averages for conception rate.

Less total lactose, protein, and fat provided by the milk resulted in calf body weight diverging by 42 days of age. Calves born to nutrient restricted dams remained smaller through weaning, when they weighed 27 kg less than control calves (Figure 2). Interestingly, calf metabolic status pre-weaning was not as severely altered as expected considering milk nutrient and calf growth differences.

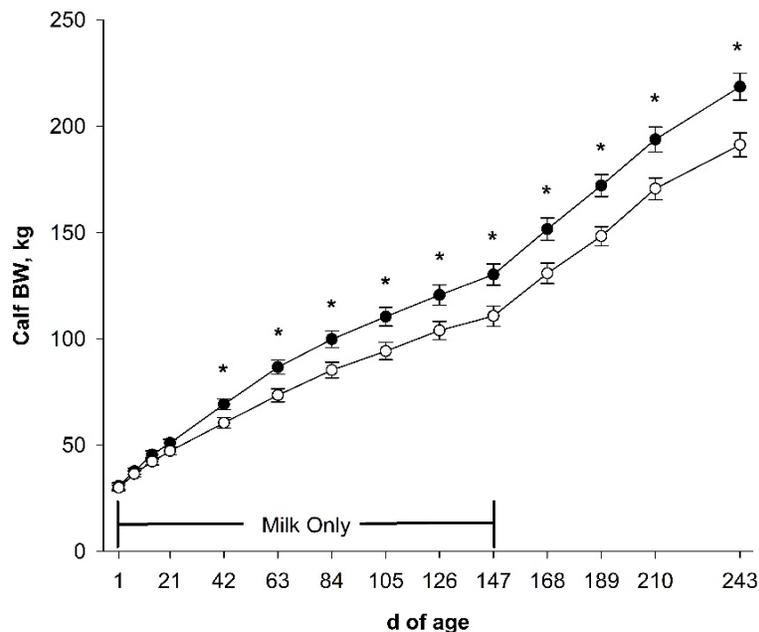


Figure 2. Effect of late gestational nutrient restriction on calf body weight (BW) from birth until weaning. Solid circles (●) represent calves born to control dams and open circles (○) represent calves born to nutrient restricted dams. *Treatment means differ ($P \leq 0.05$).

At harvest, calves born to nutrient restricted dams had lower dressing percentage, but improved yield grade and backfat thickness. Final feedlot body weight, hot carcass weight, ribeye area, and quality grade were not affected by maternal treatment.

OUTCOMES IN THE SECOND PREGNANCY AND LACTATION

Females were managed together and followed through weaning of their 2nd calf to determine if there were carryover effects during the subsequent parity (Figure 3). Previously nutrient restricted dams still weighed roughly 45 kg less and were 0.6 lower in body condition score when measured at multiple points during late gestation and lactation. Uterine blood flow, placental size, and calf birth weight were unaffected by nutrient restriction during the first pregnancy.

Colostrum yield, nutrient composition, and IgG concentrations had recovered and were similar between treatments. Milk yield and nutrient composition also recovered; however, the reduction in milk protein concentration in previously nutrient restricted dams still remained. Reduced mammary blood flow persisted in the 2nd lactation and was 18% less for previously nutrient restricted dams. During the second parity, differences in lactational performance were not severe enough to alter calf pre-weaning growth as weaning weight was similar between treatments.

Effects of nutrient restriction on second parity	
	Body weight and body condition score
	Uterine blood flow
	Placental size
	Birth weight
	Colostrum yield and composition
	Milk yield
	Milk protein concentration
	Mammary blood flow
	Weaning weight

Figure 3. Effects of late gestational nutrient restriction in the first parity on dam and offspring outcomes in the second parity

IMPLICATIONS

Although late gestational nutrient restriction may not always reduce birth weight, our results illustrate that colostrum and milk production was impaired by nutrient restriction, resulting in

decreased pre-weaning growth. Calves born to nutrient restricted dams had lighter weaning weights, which would ultimately affect cow-calf profitability. While no calves died in the research setting, it is more likely that calf malpresentations at birth, reduced calf vigor, and altered colostrum composition could lead to decreased calf survival in nutrient restricted heifers in a production setting.

Additionally, persisting effects in the 2nd parity on maternal size, fleshing ability, and mammary blood flow demonstrate the possibility of long-term programming effects on the dam, which could have implications for cow longevity in the herd. These results reinforce the importance of providing adequate nutrients to pregnant beef cattle, especially first-calf heifers that are still growing.

This work was supported by USDA-AFRI grant 2017-67015-26587 and the Illinois Beef Association.

GENOMIC TESTING IN THE COMMERCIAL HERD

Troy N. Rowan
University of Tennessee, Knoxville, TN

INTRODUCTION

We have intentionally selected and bred beef cattle for centuries to advance a wide variety of traits, improving their productivity across a range of characteristics. In recent years, the suite of tools for informing selection decisions has changed how we make these decisions. Namely, the introduction of expected progeny differences (EPDs) enables selection based on predicted genetic merit, allowing for more accurate selection. The advent of genomics in the early 2010s helped accelerate genetic gain by increasing the accuracy of EPDs for young, unproven animals. Genomics remains an invaluable tool for seedstock operations interested in advancing genetics, and for commercial bull buyers in increasing their confidence when investing in bulls.

Innovations in genotyping have led to reduced testing costs, making deployment in commercial herds practical. Routinely genotyping commercial cattle has implications for replacement heifer selection decision-making, feeder calf marketing, and designed marketing. While there are numerous advantages for commercial producers interested in implementing genomic testing in their herd, they must consider how utilizing the information can generate a return on investment.

GENOMICS AND BULL SELECTION

While directional genetic selection has occurred routinely for centuries, the concept of selection tools focused on selecting based on statistical estimates of genetic potential is relatively new (Henderson 1975). The beef industry began utilizing expected progeny differences (EPDs) to predict an animal's ability to transmit its genetic potential to offspring. By estimating just the genetic component of traits, we can make more accurate comparisons between animals across different environments & managements and make predictions in animals that will never express an important phenotype themselves (e.g., milk production in bulls). The calculation of EPDs traditionally relied on phenotypic recording by producers, aggregated at breed associations, and integrated with the breed's pedigree. In using pedigrees, genetic evaluations can effectively borrow information from relatives based on expected relationships between individuals. This assumes that full siblings are equally related to each grandparent, cousin, and so on. For this reason, genetic evaluations tended to reside within breed associations that were simultaneously tracking pedigrees within populations.

The reality of genetic inheritance is not as straightforward, as the randomness of DNA inheritance generates combinations of parental DNA that deviate significantly from the expected proportions (Figure 1). This randomness is known as Mendelian Sampling, and it can account for over 50% of the genetic variation in a trait.

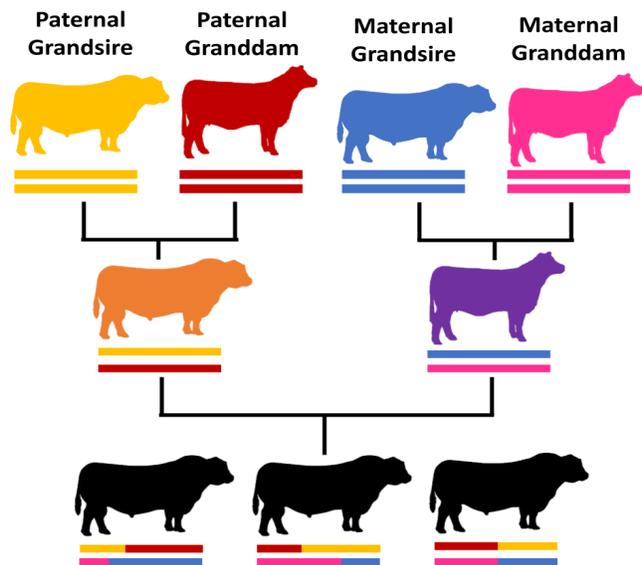


Figure 1. A graphical representation of the random inheritance of parental DNA in three full sibling bulls. Note the different degrees of relationship of each bull to their grandparents.

Because EPDs are a statistical estimate, they come with a degree of uncertainty because an animal’s “true” genetic potential is not ever definitively known. The more progeny records that an animal has contributing to its EPD, the more confident we are that the EPD represents its true genetic merit. This confidence is measured as an accuracy value that ranges from 0 to 1, where increasing accuracies indicate increased confidence that the EPD represents the animal’s additive genetic potential. Due to limited information, purchasing young, unproven sires carries economic risk, as an animal’s EPD may not sufficiently represent the true genetic potential. This

Because EPDs are a statistical estimate, they come with a degree of uncertainty because an animal’s “true” genetic potential is not ever definitively known. The more progeny records that an animal has contributing to its EPD, the more confident we are that the EPD represents its true genetic merit. This confidence is measured as an accuracy value that ranges from 0 to 1, where increasing accuracies indicate increased confidence that the EPD represents the animal’s additive genetic potential. Due to limited information, purchasing young, unproven sires carries economic risk, as an animal’s EPD may not sufficiently represent the true genetic potential. This

In the late 2000s, the first genomic tests were introduced to the beef industry (Matukumalli et al. 2009), enabling the integration of actual DNA content into EPD calculations (Meuwissen, Hayes, and Goddard 2001). We refer to these as genomically-enhanced EPDs (GE-EPDs). The inclusion of genomic information results in increased EPD accuracy, particularly for young, unproven animals without progeny records. In practice, this means that bulls who have never sired a calf can receive the same increase in EPD confidence as a bull would if 20-30 progeny had entered the genetic evaluation (Angus Genetics Inc., 2025). **Table 1** shows “progeny equivalents” for various traits reported by the American Angus Association. These can be interpreted as the number of progeny needed in the genetic evaluation to generate the same accuracy as a genomic test. The increase in accuracy provided by genomics varies by trait and is a function of the number of records in the genetic evaluation and the trait's heritability.

Table 1. Genomic test progeny equivalents for select traits in Angus genetic evaluation

Trait	Progeny Equivalents
Calving Ease (CED)	24
Weaning Weight (WW)	25
Yearling Weight (YW)	20
Mature Weight (MW)	14
Heifer Pregnancy (HP)	28
Milk (MILK)	33
Marbling (MARB)	10

Source: American Angus Association

These can be interpreted as the number of progeny needed in the genetic evaluation to generate the same accuracy as a genomic test. The increase in accuracy provided by genomics varies by trait and is a function of the number of records in the genetic evaluation and the trait's heritability.

The introduction of genomic testing into the seedstock industry affected multiple areas of breeding programs. It both helped increase

selection accuracy and reduce generation intervals by identifying superior genetic potential animals earlier in their lives (Garrick and Golden 2009). This resulted in across-the-board improvements in the rate of genetic progress (Retallick et al. 2022).

GENOMIC TESTING FOR COMMERCIAL HEIFERS

Genomic testing's largest benefits to commercial herds come from the increased accuracy of selection of herd sires. This risk mitigation helps assure that commercial operations invest resources in the right bulls to advance their intended genetic goals. Currently, testing is nearly ubiquitous in seedstock herds, as a clear return on investment can be derived from testing sale bulls, as well as high-value replacement females (Van Eenennaam and Drake, 2012). As prices of genomic testing have dropped into the \$20 range, the potential to generate returns on this investment is becoming attainable in the commercial cow-calf sector.

Commercial Genomic Test Validations

Work by Arisman and colleagues (2023) used a set of genotyped commercial cows at the University of Missouri to validate the results from the Zoetis GeneMax Advantage, a genomic test designed for straightbred (>75%) Angus females. The Genemax reports genetic potentials on a scale of 0-100 for a variety of pre- and post-weaning traits of economic importance. This work validated the predictions by regressing calf performance on the dam GeneMax score. Across all

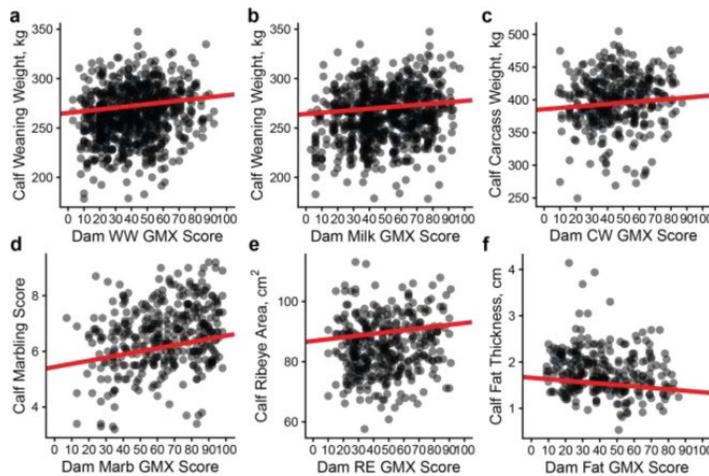


Figure 2. Plots depicting the linear relationships between Dam genomic score and offspring actual performance across a range of traits reported on the GeneMax Advantage (from Arisman et al. 2023).

traits, cow genomic scores were predictive of eventual calf performance when year-to-year variation, sire, and sex were controlled for. Figure 2 shows the linear relationships between cow genomic scores and the performance of calves. Model correlations ranged from 0.09 to 0.45 across various traits, indicating that these genomic tests possess moderate predictive abilities that exceed the heritabilities of the traits of interest. Furthermore, the effects estimated in this study were similar to those published by Zoetis. Other ongoing work is occurring across the industry to more robustly test the predictive ability of these tests and model their value

Types of Commercial Genomic Evaluations

Commercial genomic tests fall into three main categories, each with its own advantages and disadvantages. Operations interested in genomic testing should consider breed composition and the level of record-keeping when choosing the best genotyping route for their needs.

Commercial Whole Herd Reporting

Some breed associations allow for the inclusion of commercial animals in their genomic evaluations. These schemes enroll commercial herds in a whole herd reporting scheme (Giess et al. 2021) alongside seedstock herds. These evaluations produce the same suite of EPDs that purebred animals would receive and offer the opportunity for genomic enhancement. The primary benefit of these programs is that they are of equivalent accuracy to breed association-reported EPDs. Genetic predictions are also informed by real records from related individuals in the herd, as well as the selection candidates themselves. This high-accuracy option for genomic predictions has tradeoffs with ease of use, as it requires substantial record-keeping, on the same level as what a seedstock herd would be expected to do.

Single Breed Genomic Tests:

The most notable single-breed genomic test is the Zoetis GeneMax Advantage, designed for animals with > 75% Angus Ancestry. These tests are made possible by leveraging large sets of genotypes from registered populations, and using marker effects to predict in the genotyped commercial animals. Unlike the whole herd reporting schemes, these tests do not require any data reporting on the producer's behalf. As such, they do sacrifice some on prediction accuracy. However, the high level of relationship between tested straightbred animals and the training population makes their predictions of general high quality.

Multi-Breed Genomic Tests:

These tests make up the largest share of commercial genotypes, headlined by Zoetis Inherit Select and the Neogen Igenity panels. These tests are suitable for crossbred commercial cattle, balancing ease of use with flexibility across most herds. They do sacrifice a bit of accuracy compared with straightbred tests, but are still valuable tools for estimating a heifer's genetic potential.

Using Commercial Heifer Genomic Tests

New genomic products allow commercial heifers to receive genetic predictions for multiple relevant traits. While not the same GE-EPDs in most cases, these still provide valuable context about the genetic potential of a female. Traditionally, heifer selection was based on phenotypic performance, age, or cow family. Genomic tests provide EPD-like information to aid in choosing heifers, in addition to other, more conventional methods. It is essential to note that these tests only estimate the genetic components of traits and do not provide phenotypic predictions. So, for lowly heritable traits like fertility, they may only account for ~5% of the animal's actual phenotype.

Additionally, to generate a return on investment, herds must test more heifers than they plan to keep. Generally, testing at least twice as many heifers as there are replacement slots is best practice. Testing heifers that are clear phenotypic culls (too young, unfavorable pelvic scores, etc.) is not advised, as the genomic test results would not alter the selection decision. Conversely, genomically testing only heifers that were already identified as selection candidates defeats the purpose of adding this extra layer of information to the decision.

Beyond identifying heifers with high genetic potentials for economically relevant traits, genomic testing also helps operations identify bulls that can fill in potential genetic shortcomings of replacements. Better enabling complementary matings may provide the greatest return on investment from genomic tests.

Finally, genomic tests help identify the potential for heterosis to be expressed across traits in crossbred females. Many of the most essential traits for a female's long-term success are lowly heritable, such as fertility, health, and longevity. These lowly heritable traits are the ones that respond the most favorably to heterosis in crossbreeding systems (Gregory, Cundiff, and Koch 1992). Genomics can be a useful tool for identifying animals with greater potential for expressing heterosis across traits (Akanno et al. 2017). These include genome-wide heterosis (% of heterozygous markers) and genomic retained heterozygosity based on the genomically-determined breed fractions. Commercial genomic tests enable producers to incorporate the heterosis potential of replacements into their selection decisions, a previously unaccountable metric when evaluating individuals phenotypically within a group of likely similar breed compositions.

GENOMIC TESTING FOR TERMINAL CATTLE

Source verification and added-value marketing programs have been excellent tools for helping producers capture additional profits by implementing improved health protocols and record-keeping. Dozens of programs exist that validate to buyers that a group of calves has been exposed to some sort of best management practices. Calves with verifiable health protocols, managed by a Beef Quality Assurance (BQA) certified producer, carry significantly less risk of disease and exhibit decreased performance in the feedlot. As such, buyers are willing to pay premiums for these cattle. While management plays an essential role in a calf's performance post-weaning, understanding a calf crop's genetic potential for feedlot and carcass performance is invaluable information for buyers. Recent developments across the industry are creating opportunities to add further value to feeder calves based on the genetic merit of their sires or through genomic testing.

While sire-focused genetic programs often provide adequate estimates of a calf crop's genetic potential, genomic testing can sometimes offer a more precise picture of the group's underlying genetic makeup. In scenarios where multiple sire breeds are used, genomic tests allow producers to quantify the average genetic potential of an entire group of calves. Moreover, as the cost of genotyping assays has declined, it has become increasingly practical to test feeder calves directly. Some producers even leverage genomic test results from replacement heifers to infer steer calf potential and bolster marketing claims (DeLong et al. 2023).

Genomic tests produce continuous scores for the genetic potential of various traits and indices, depending on the provider and program. Typically, these scores derive from marker effects estimated in large training sets. For example, the Igenity Feeder Calf Test (Neogen) uses marker effect estimates from the IGS genetic evaluation to generate trait scores and combine them into a terminal index that classifies cattle as either Elite (top 25 %), Premier (top 50 %), or Choice (tested but not in the top percentiles).

Genomic testing of feeder calves represents an exciting development in the cattle industry, yet the technology continues to evolve. Despite reliance on large training datasets to estimate marker effects, potential accuracy for feeder-calf genomic tests still lags behind the accuracy of EPDs derived from a national genetic evaluation program (DeLong et al. 2023; Newton, Hayes, and Pryce 2018). Because feeder-calf genomic tests are typically more expensive than sire-verification programs, cost can be managed by sampling only a portion of the calf crop (for example, over 35 % in some Igenity programs) and extrapolating the average genetic score of the sampled animals to the remainder of the group (Beef Cattle Genetics Value-Added Programs fact-sheet, 2023).

The potential to include genomic tests in feeder cattle purchasing and management is exciting, but it remains in its infancy. Genomic tests could be used to identify animals with similar genetic potentials for end-product quality to group for marketing in premium programs, or to assemble pens based on genomically predicted days on feed. For genomic testing to make a significant impact on the feeder cattle sector, it will need to continue its price decline, and markets must demand or pay appropriate premiums for tested animals.

CONCLUSIONS

Genomic testing has had a significant impact on the beef industry since its introduction. Its most profound effects have always been in advancing seedstock genetics and helping increase the accuracy of EPDs used in bull selection. Recently, costs have dropped, making genomic testing more practical for commercial herds. Genomic tests provide valuable information for replacement heifer retention decisions and may offer additional marketing opportunities for terminal cattle. Implementing genomic testing requires a clear understanding of how it can generate value on a herd-by-herd basis.

REFERENCES

- Akanno, E. C., L. Chen, M. K. Abo-Ismael, J. J. Crowley, Z. Wang, C. Li, J. A. Basarab, M. D. MacNeil, and G. Plastow. 2017. “Genomic Prediction of Breed Composition and Heterosis Effects in Angus, Charolais, and Hereford Crosses Using 50K Genotypes.” *Canadian Journal of Animal Science* 97 (3): 431–38.
- Arisman, Brian C., Troy N. Rowan, Jordan M. Thomas, Harly J. Durbin, William R. Lamberson, David J. Patterson, and Jared E. Decker. 2023. “Evaluation of Zoetis GeneMax Advantage Genomic Predictions in Commercial Bos Taurus Angus Cattle.” *Livestock Science* 274 (August): 105266.
- DeLong, Karen L., Kimberly L. Jensen, Andrew P. Griffith, Christopher N. Boyer, and Charley C. Martinez. 2023. “Feeder Cattle Genomic Tests: Analyzing Cattle Producer Adoption Decisions.” *Journal of the Agricultural and Applied Economics Association*, May. <https://doi.org/10.1002/jaa2.61>.
- Garrick, D. J., and B. L. Golden. 2009. “Producing and Using Genetic Evaluations in the United States Beef Industry of Today.” *Journal of Animal Science* 87 (14 Suppl): E11-8.
- “Genomic-Enhanced EPDs.” 2025. Angus Genetics Incorporated. 2025. <https://www.angus.org/agi/genomic-enhanced-epds>.

- Giess, Lane K., Milton G. Thomas, Scott E. Speidel, Miranda M. Culbertson, Wade R. Shafer, Steve C. McGuire, and R. Mark Enns. 2021. "Whole Herd Reporting Data from the American Simmental Association as a Data Source for Heifer Pregnancy Phenotypes." *Translational Animal Science* 5 (Supplement_S1): S199–203.
- Gregory, K. E., L. V. Cundiff, and R. M. Koch. 1992. "Breed Effects and Heterosis in Advanced Generations of Composite Populations for Reproduction and Maternal Traits of Beef Cattle." *Journal of Animal Science* 70 (3): 656–72.
- Henderson, C. R. 1975. "Best Linear Unbiased Estimation and Prediction under a Selection Model." *Biometrics* 31 (2): 423–47.
- Matukumalli, Lakshmi K., Cynthia T. Lawley, Robert D. Schnabel, Jeremy F. Taylor, Mark F. Allan, Michael P. Heaton, Jeff O'Connell, et al. 2009. "Development and Characterization of a High-Density SNP Genotyping Assay for Cattle." *PloS One* 4 (4): e5350.
- Meuwissen, T. H., B. J. Hayes, and M. E. Goddard. 2001. "Prediction of Total Genetic Value Using Genome-Wide Dense Marker Maps." *Genetics* 157 (4): 1819–29.
- Newton, J. E., B. J. Hayes, and J. E. Pryce. 2018. "The Cost-Benefit of Genomic Testing of Heifers and Using Sexed Semen in Pasture-Based Dairy Herds." *Journal of Dairy Science* 101 (7): 6159–73.
- Retallick, K. J., D. Lu, A. Garcia, and S. P. Miller. 2022. "431. Genomic Selection in the US: Where It Has Been and Where It Is Going?" In *Proceedings of 12th World Congress on Genetics Applied to Livestock Production (WCGALP)*, 1795–98. 431. Wageningen Academic Publishers.
- Van Eenennaam, Alison L., and Daniel J. Drake. 2012. "Where in the Beef-Cattle Supply Chain Might DNA Tests Generate Value?" *Animal Production Science* 52 (3): 185–96.

IMPACT OF RANCH DECISIONS ON CALF VALUE IN THE FEEDYARD

Warren Rusche
Department of Animal Science
South Dakota State University

INTRODUCTION

I attended my first Range Beef Cow Symposium in 1997 in Rapid City, SD as a young Extension Educator. At that time, one of the primary themes was that the beef industry needed to improve product quality to meet consumer demands, and if the industry failed, we were going to be doomed to lose the battle for the center of the plate to chicken or pork.

How things have changed in the last 28 years. We are witnessing the fruits of a sea change in how our business has responded to the challenge posed to us in Rapid City. One only needs to look at a retail shelf and see the price difference between a rib eye steak and a boneless pork chop and come away with the conclusion that one industry's product is a sought-after, high-value item, and another must try to gain sales by cutting prices. That is not to say that our industry does not face challenges. Drought, labor availability, and news events both here and globally all impact this business today and will in the future. However, the strong demand base we have established is positive for setting a foundation for cattle values.

One could be tempted to look at this landscape and conclude that all a rancher needs to do today to be successful is get cows bred and produce live calves. That sentiment is justifiable, and in the short term true considering where feeder calf values are today. However, differences in cattle value exist, and may even widen under these new conditions.

WHAT ARE CATTLE FEEDERS LOOKING FOR?

Although market conditions have changed, what cattle feeders are seeking has stayed constant. As I visit with cattle feeders, these three items top their "wish list":

- Cattle that stay healthy.
- High-performing cattle as indicated by high ADG and improved feed efficiency combined with the ability to finish at a greater weight.
- Ability to capture carcass premiums with manageable discounts.

Every factor identified as influencing feeder calf value can be traced back to one of those three attributes. For instance, in a recent multi-state survey, lot size, vaccination and weaning status, frame/muscle scores, and coat color were identified as key factors influencing feeder cattle auction prices (Peel et al., 2023). Larger lot sizes mean less co-mingling in the feedyard, which should reduce risk of feedlot death loss, along with a documented vaccination history. Frame and muscle descriptions provide some guidance regarding future feedlot performance, and the industry has used coat color as a proxy to predict carcass quality. For the balance of this paper, I will attempt to discuss these factors in more detail, and to describe how changes in the cattle market have affected the relative influence of these factors.

HEALTH STATUS

Although a number of health conditions can impact feeder cattle such as lameness and digestive disorders, mortality and sickness caused by bovine respiratory disease (BRD) is the costliest health issue facing feedlots, especially in newly weaned/received cattle (Duff and Galyean, 2007). While death loss, and to a lesser extent treatment costs would appear to be the most obvious sources of monetary losses, BRD also impacts performance and carcass merit. Cattle that were treated more frequently gained more slowly with fewer carcasses grading in the upper two-thirds of the choice grade (Reinhardt et al., 2012). Comparable results were reported by Busby et al., (2004) with their work also showing poorer feed efficiency in cattle that required treatment compared to those that did not.

None of the preceding paragraph is added information, as the importance of health status is widely accepted. What has changed are the dollar values at stake. An example of the economic impact of death loss is shown in Table 1. This data from a larger closeout database divides closeout records for 650–700-pound heifers into categories based on the dollars available to pay for the calf, after accounting for final income and all other costs. In this dataset, the range from the most to least valuable was approximately \$580 per head. All performance data presented is on a dead-in basis, meaning that all costs for dead cattle are included. One can see how tight profitability and mortality track. Obviously, these are not current values of cattle, but they illustrate the point. If anything, the value spread has widened simply because they are dramatically more valuable than just a few years ago.

PERFORMANCE AND CARCASS WEIGHT

The reasons that faster growth and improved feed efficiency are important components to feedlot cattle profitability are obvious; faster gaining cattle that require less feed per pound of gain have a lower cost of gain and better odds of being profitable compared to their slower gaining, less efficient counterparts. As discussed above, health status is a critical component, along with genetic growth potential and factors such as condition or fill.

Increased finish weight (and carcass weight) is also a key factor in profitability (Walter and Hale, 2012; Walker and Rusche, 2014). At one point, I would have qualified that statement by saying if discounts for overweight carcasses can be avoided. That is less of a concern now. As we study growth and carcass gain relative to live performance, the feeding industry has realized that we can profitably feed cattle to heavier weights. The idea that we dilute purchase price by spreading that investment out over a greater quantity of saleable pounds is not new. What is new is that if we are selling cattle on a carcass weight basis, we do not see a drop in efficiency as quickly as we do with live sales.

There has been a consistent and predictable increase in carcass weight over time. As shown in Figure 1, carcass weight has increased by an average of 4.5 pounds per year since 1962. This increase in output is a primary reason the U.S. beef industry has been able to maintain beef supplies even though cow herd inventories have shrunk. This trend of increasing hot carcass weight shows no signs of slowing down, despite concerns about primal and retail cut size.

Several researchers have examined carcass gain relative to live weight (Galyean et al., 2023; Martinez et al., 2023; Sperber et al., 2024) and they have found that steer increase hot carcass weight by approximately 2 pounds per day. Those studies stopped at 1500-pound live weight for steers. We recently completed a study where we took steers to a slaughter weight of approximately 1700 pounds (Olinger et al., 2025b), where we observed the same response (2.16 and 1.78 pounds daily carcass gain for steers and heifers, respectively). With near constant increases in carcass gain and similar intakes, the net result is a marginal cost of gain per pound of carcass nearly constant over an extended feeding period.

In that study we also examined the effect of extending days on feed on profitability. The cost and value assumptions we used are shown in Table 2 and reflect the economic condition of summer 2024 when these cattle were fed and marketed. Initial feeder calf value (not shown) was calculated using each animal's on test weight and prices derived from USDA AMS data for the week of study initiation. Profitability by feeding length is shown in Figure 2. As you can see, adding days on this set of cattle resulted in greater profit per head. We see this play out in management and marketing decisions made by cattle feeders.

CARCASS PREMIUMS AND DISCOUNTS

The other factor affecting slaughter cattle value, and feeder cattle value as well, is the impact of carcass premiums and discounts. Discounts for yield grade and heavy-weight carcasses are controlled by marketing decisions at the feedlot. On the other hand, the potential for quality grade premiums and discounts are controlled by genetic decisions made on the ranch. As mentioned in

the introduction, the beef industry has made tremendous strides in improving the quality and eating satisfaction of the product we produce, and it would be a mistake to undo those gains.

Fortunately, it is possible to achieve both efficient growth, increased output, and higher quality at the same time. The extended days on feed study mentioned earlier used steers and heifers sired by Angus, Limousin, or Lim-Flex bulls (Olinger et al., 2025a). The averages for each sire group are listed in Table 3. Although these are categorized by sire breed, we can also think of these as descriptions of cattle type. For instance, the Angus-sired cattle in this dataset were high-quality but were the fattest and least efficient of this group. On the other hand, the Limousin-sired cattle were characterized by leaner carcasses and the most efficient feedlot gains but did not place any cattle into the Prime grade. The Lim-Flex sired group represented an improvement compared to the other two sets as they were similar in Quality grades to the Angus with the advantages of more cutability and feed efficiency.

The power of combining greater carcass price with increased output is shown in Figure 3. All three breed types increased in profitability as days on feed were added. However, those groups of cattle that captured more premiums because of improved carcass quality showed a greater return by increasing days on feed and sale weight.

HOW DOES A RANCHER USE THIS INFORMATION TO ADD VALUE?

The discussion of the importance of reducing health risk in feeder cattle should surprise no one as this has been a topic of discussion for many years. I will not go into depth in these proceedings on recommendations for vaccination or animal health protocols as there are multiple resources available. Ranchers should visit with their herd veterinarian as well as veterinarians that work with feedlots to devise strategies that reduce risk as calves transition to the feedlot. Evaluation of nutritional programs would also be warranted as we gain greater understanding of the impact of maternal nutrition on subsequent health status of calves.

As evidenced by the improvement in carcass quality made by the U.S. beef industry, we have done an excellent job of improving genetics for marbling while increasing growth potential, so I doubt that any suggestions that we maintain that focus would be controversial. That is not true when it comes to a discussion of a demand for increased carcass weight and how that might affect mature cow size. As I wrote earlier, in my opinion the market signals for greater carcass weight potential are not going away. There may well be an upper limit to what we can sustainably produce which will likely be dictated by cattle health challenges with larger animals in the feedlot and environmental constraints at the ranch.

I want to stress that I am not suggesting or implying that ranchers should increase the mature size of their cows. Cows must first function on that ranch environment and it would be a serious mistake

to blindly chase increased output without a serious considerations of all the consequences involved, intended and unintended. However, there are strategies that can be used to produce feeder cattle with increased potential carcass weight without requiring wholesale changes in the cow herd.

First, there are opportunities to make greater use of strategic sire selection for replacements and feeder calves. Using multi-purpose bulls does simplify management but gives up the opportunity to use targeted sire selection to create cattle that more closely fit herd objectives. The genetics selection tools we have available are quite good today, particularly for output traits such as growth and carcass characteristics. Greater use of terminal sires (regardless of breed choice) would increase revenue for many ranches today.

Secondly, we can make greater use forage-based strategies to grow and “frame out” cattle from more moderate gene pools. For ranchers or cattle feeders with the necessary resources, this strategy increases marketing options and production flexibility. Our experience feeding cattle that have been wintered on forage and summered on grass has been that those cattle grow exceptionally well and can be taken to heavy weights easily. There is a need for additional research on how to better use forage (annual or permanent) resources to increase beef production and improve ranch resilience.

Finally, the industry needs to find better ways to identify and value cattle with the attributes that I have described in this paper. I think we can do better than relying on descriptions such as “black, good, and had all their shots” to predict outcomes and value. I am hopeful that new tools on the horizon that transmit genetic and health information from ranches to feedlot will bridge that gap. That belief may be hopelessly naïve, but I also remember sitting in a hotel ballroom in 1997 listening to speakers outline all the challenges facing our industry and then witnessing the successes and advancements that we have made since that time. If we were able to solve that challenge, I am confident that we have the capability to solve these concerns as well.

TABLES AND FIGURES

Table 1. Effect of death loss and performance measures on profitability in 675-pound heifers (all values dead-in basis)

Lots, #	Initial weight, lbs	Final weight, lbs	ADG, lbs	Feed conversion	Mortality, %	Value, \$/hd	Variation from Average
2	655	1190	1.34	14.39	28.8	558.66	-382.79
3	675	1201	1.72	13.96	20.7	591.65	-349.80
5	672	1113	1.52	11.44	15.4	637.52	-303.93
8	666	1193	2.12	9.27	12.4	713.55	-227.90
34	668	1201	2.25	8.37	11.2	758.50	-182.95
71	668	1197	2.47	7.63	7.8	803.23	-138.22
176	670	1195	2.69	7.08	4.8	853.15	-88.30
444	670	1204	2.93	6.63	2.5	903.64	-37.81
833	677	1223	3.15	6.27	1.6	951.32	9.87
523	679	1263	3.37	6.09	1.1	995.83	54.38
144	681	1316	3.59	5.97	0.7	1043.18	101.73
11	686	1347	3.79	5.63	0.7	1087.54	146.09
3	683	1362	3.44	4.95	0.0	1138.82	197.37
2,257	673	1231	2.65	6.45	2.3	941.45	0

(Courtesy Pete Anderson, Midwest PMS)

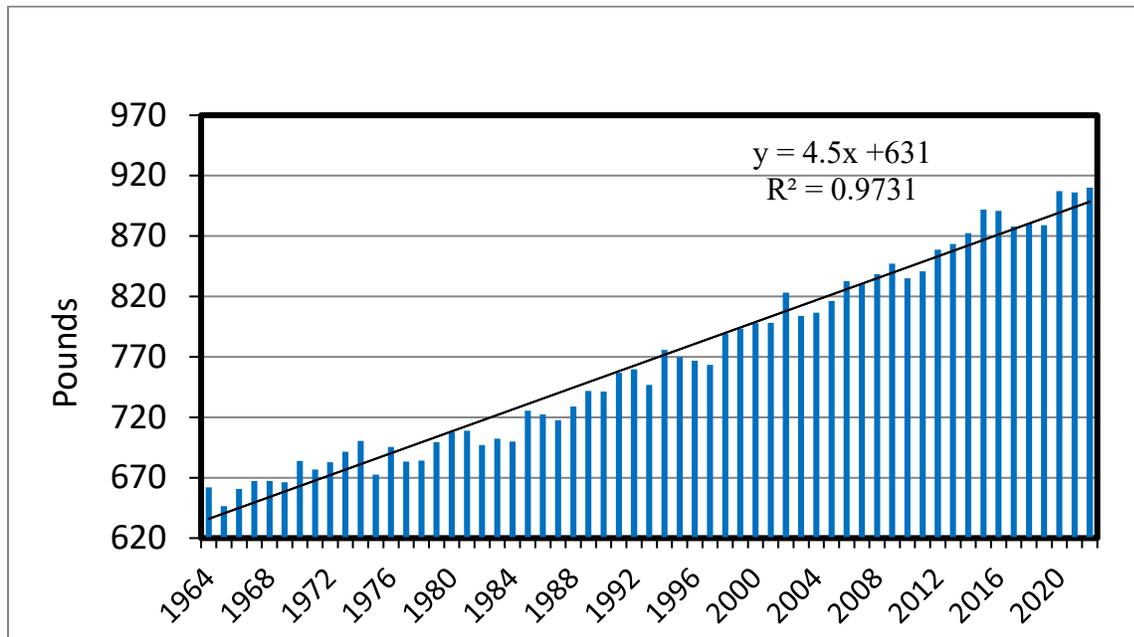


Figure 1. Steer dressed weights (1962-2022), federally inspected slaughter. Source: USDA-NASS, Livestock Marketing Information Center.

Table 2. Cattle value and cost assumptions for days on feed analysis.

Factor	Value
Base price, \$/cwt	\$310
Prime	\$20
Certified Angus Beef	\$6
Select	\$-20
YG 1	\$3
YG 2	\$1
YG 4	\$-5
YG 5	\$-14
HCW > 1100 lbs	\$-15
Diet cost	\$200 per ton, dry matter
Yardage	\$0.50 per day
Interest	8.5%

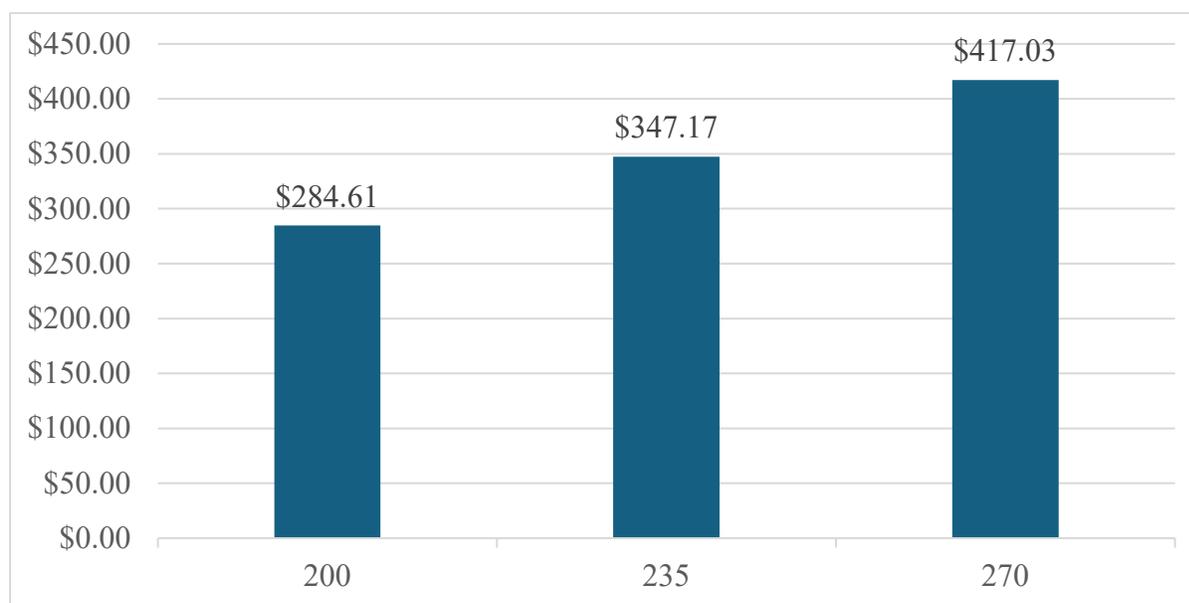


Figure 2. Feeder cattle profitability for 200, 235, or 270 days on feed. Average hot carcass weights were 872, 946, and 1009 pounds for 200, 235, and 270 days, respectively. (Olinger 2025, unpublished data).

Table 3. Carcass and performance averages for steers and heifers sired by Angus, Lim-Flex, or Limousin bulls and fed for 200, 235, or 270 days.

	Sire Breed		
	Angus	Lim-Flex	Limousin
Hot carcass wt., lbs	936	941	948
Feed conversion	6.7	6.5	6.3
Ave, Yield Grade	3.8	3.5	3.3
Prime, %	17	16	--
Premium Choice, %	49	53	48
Low Choice, %	28	24	51
Select	7	7	1
YG 4 & 5, %	40	26	24

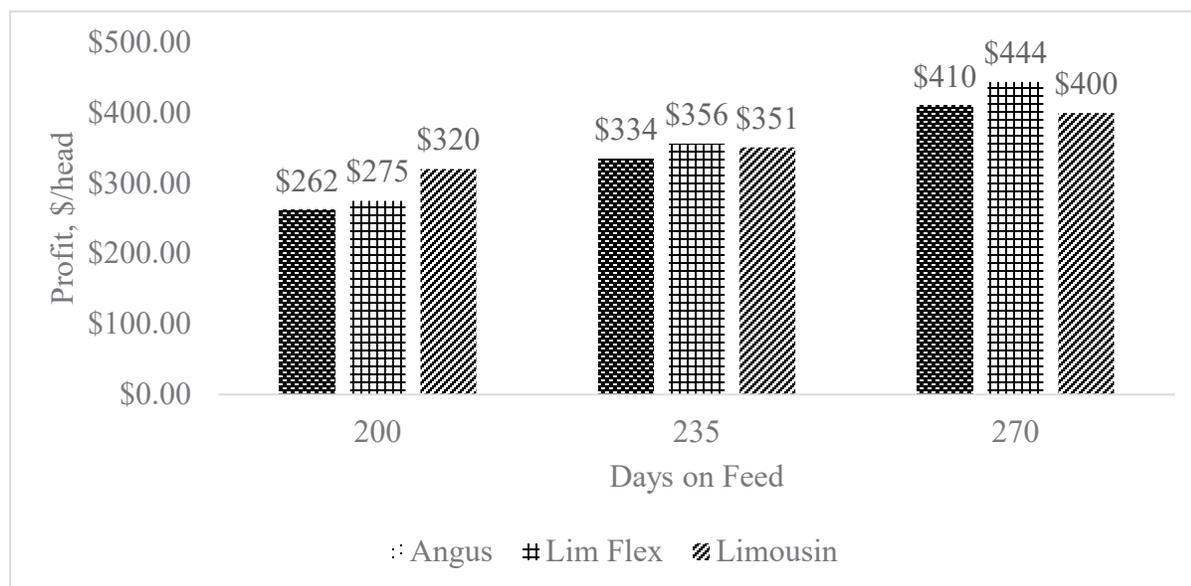


Figure 3. Profitability (\$/head) for steers and heifers sired by Angus, Lim-Flex, or Limousin bulls fed for 200, 235, or 270 days (unpublished data).

REFERENCES

- Busby, W.D., D.R. Strohbehn, P. Beedle, and L.R. Corah. 2004. Effect of postweaning health on feedlot performance and quality grade. Iowa State University Animal Industry Report. A.S. Leaflet R1885.
- Duff, G.C. and M.L. Galyean. 2007. Board-Invited Review: Recent advances in management of highly stressed newly received feedlot cattle. *J. Anim. Sci.* 85:823-840.
- Galyean, M. L., Nichols, W. T., Streeter, M. N., Hutcheson, J. P. 2023. Effects of Extended Days on Feed on Rate of Change in Performance and Carcass Characteristics of Feedlot Steers and Heifers and Holstein Steers. *Applied Animal Science*, **39**(2): 69-78.
<https://doi.org/10.15232/aas.2022-02366>
- Martinez, S. L., Word, A. B., Holland, B. P., Karr, K. J., Hutcheson, J. P., Walter, L. J., Richeson, J. T., Lawrence, T. E., Samuelson, K. L. 2023. Effects of Growth-Implant Regimen on

Performance, Carcass Outcomes, Activity, and Rumination of Finishing Steers Fed to Different Days on Feed. *Applied Animal Science*. 39(6): 456-471.

<https://doi.org/10.15232/aas.2023-02424>

- Olinger, G., Z. Smith, F. Francis, B. G. Francis, R. Leeson, M. Gonda. R. L. Weaver, and W. Rusche. 2025a. Effect of steers and heifers of different proportion of Angus and Limousin genetics on growth performance, efficiency, and carcass characteristics. SDSU Animal Science Research and Extension Report. Pp. 83-85. Available at <https://extension.sdstate.edu/sites/default/files/2025-07/P-00347.pdf>.
- Olinger, G., Z. Smith, F. Francis, B. G. Francis, R. Leeson, M. Gonda. R. L. Weaver, and W. Rusche. 2025b. Effect of extended days on feed on growth performance, efficiency, and carcass characteristics of steers and heifers of different proportions of Angus and Limousin genetics. SDSU Animal Science Research and Extension Report. Pp. 86-88. Available at <https://extension.sdstate.edu/sites/default/files/2025-07/P-00347.pdf>.
- Peel, D. S., E. McGill, K. Curry Raper and E. A. DeVuyst. 2023. Value indicators of feeders cattle: An analysis of multi-state auction data. USDA Agriculture Market News. Available at: [Value Indicators in Feeder Cattle:](#)
- Reinhardt, C.D., M.L. Hands, T.T. Marston, J.W. Waggoner, and L.R. Corah. 2012. Relationships between feedlot health, average daily gain, and carcass traits of Angus steers. *Prof. Anim. Sci.* 28:11-19.
- Sperber, J. L., Bondurant, R. G., Erickson, G. E., Bruns, K., Funtson, R. N., MacDoncald, J. C. 2024. Effect of Extended Days on Feed on Carcass Gain, Efficiency, and Quality of Individually Fed Beef Steers. *Translational Animal Science* <https://doi.org/10.1093/tas/txae081>
- Walker, J.A., and W.C. Rusche. 2014. SDSU Calf Value Discovery 2012/2013 Summary Report. SDSU Animal Science Beef Report. Beef 2013-07. Brookings, SD. Available at: <http://sdstate.edu/ars/species/beef/beef-reports/upload/7-Walker-Calf-Value-Discovery.pdf>
- Walter, S., and R. Hale. 2012. Profit profiles: Factors driving cattle feeding profitability. Available at: <http://www.cabpartners.com/articles/news/2553/CAB%20Profit%20Profiles%202010-2011%20update.pdf>

PULMONARY HYPERTENSION: NEW RESEARCH AND DEVELOPMENTS

Scott E. Speidel and R. Mark Enns
Department of Animal Sciences
Colorado State University

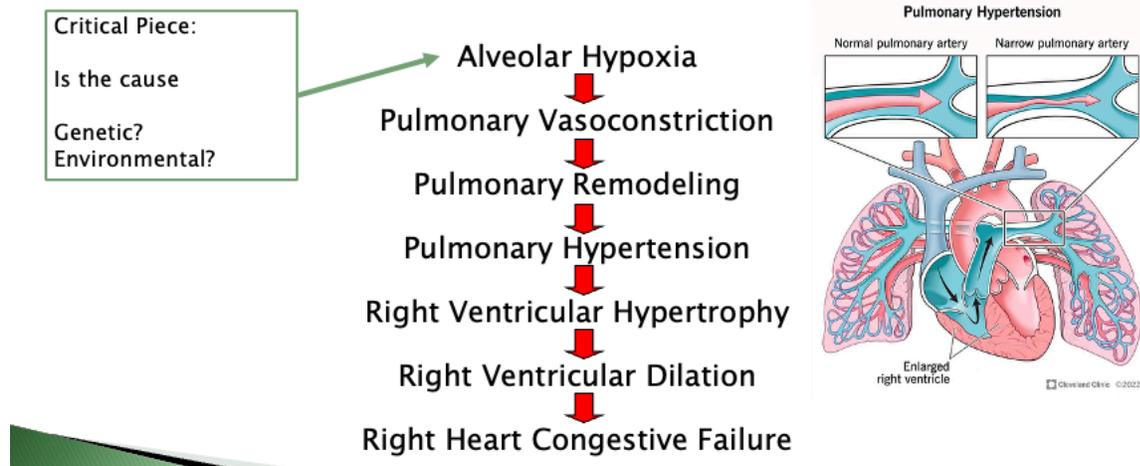
INTRODUCTION

First reported in an academic report by Glover and Newsom in 1915, high altitude disease (HAD), otherwise known as “Brisket Disease,” had been observed much prior to that, as early as 1889 in the South Park of Colorado. In the early 1900’s the disease was often misdiagnosed as diphtheria. Over 130 years later, while much more is known about the disease, research is ongoing to fully understand both the biology underlying the disease and its triggers. While HAD is triggered by lower oxygen concentrations in the atmosphere associated with increasing elevation, increasingly severe clinical signs of the disease are now being observed at elevations much lower than in the past and are being reported with increasing frequency in moderate-elevation feedlots. Underlying both problems is pulmonary hypertension

REVIEW OF PULMONARY HYPERTENSION

With time and research, a better understanding of pulmonary hypertension underlying HAD has developed. The lower levels of available oxygen at high elevations lead to alveolar hypoxia in the lungs, which, in turn, triggers a physiological cascade (see Figure 1) in susceptible animals, leading to pulmonary remodeling. In susceptible animals, the

Figure 1. Progression of pulmonary hypertension (courtesy Dr. Tim Holt)



hypoxia results in pulmonary hypertension as a result of remodeling of the pulmonary artery. In turn, this causes right ventricular hypertrophy, which can ultimately result in right-sided heart congestive failure and death.

The severity of pulmonary hypertension can be assessed by measuring pulmonary arterial pressure (PAP). From a cattle producer's standpoint, the question becomes to what extent genetics contributes to the incidence of the disease versus environmental factors. Research has shown that there is considerable genetic influence on PAP, with heritability estimates ranging from .25 to .46, where heritability is the proportion of observed variability due to underlying additive genetics. These estimates for PAP are in line with many traits that producers have historically improved through genetic selection, such as weaning weight, milk, marbling score, and carcass weight. Given the significant genetic influence on pulmonary arterial pressure, several organizations and breed associations have developed expected progeny differences (EPDs) for PAP. These EPDs provide breeders with a tool to select animals better adapted to high-altitude environments, with the expectation that progeny will have a lower incidence of HAD. These organizations include the American Angus Association, International Genetic Solutions, and Leachman Cattle of Colorado. These EPD are the result of breeders reporting PAP observations, contemporary group, and genomic information, which is then combined and analyzed to produce the EPD.

The development and delivery of PAP EPD to breeders have raised questions about the appropriate elevations for recording PAP measures when those observations are used to produce EPD as accurate as possible. Three studies have shown a strong relationship between PAP at elevations above approximately 5,250 feet and PAP recorded between 3,000 and 5,250 feet. Speidel et al. (2020), Culbertson et al. (2017), and Pauling et al. (2018) have all shown that the genetic correlation between PAP measured at moderate elevations and those measured at high elevations is above .70, much like the genetic relationship between ultrasound measures of carcass quality and performance of harvest progeny on the rail. This is encouraging, as it provides the opportunity to include PAP observations from moderate elevations, increasing the amount of data used to calculate EPD and, therefore, resulting in higher accuracy.

PULMONARY HYPERTENSION IN FEEDLOT ANIMALS

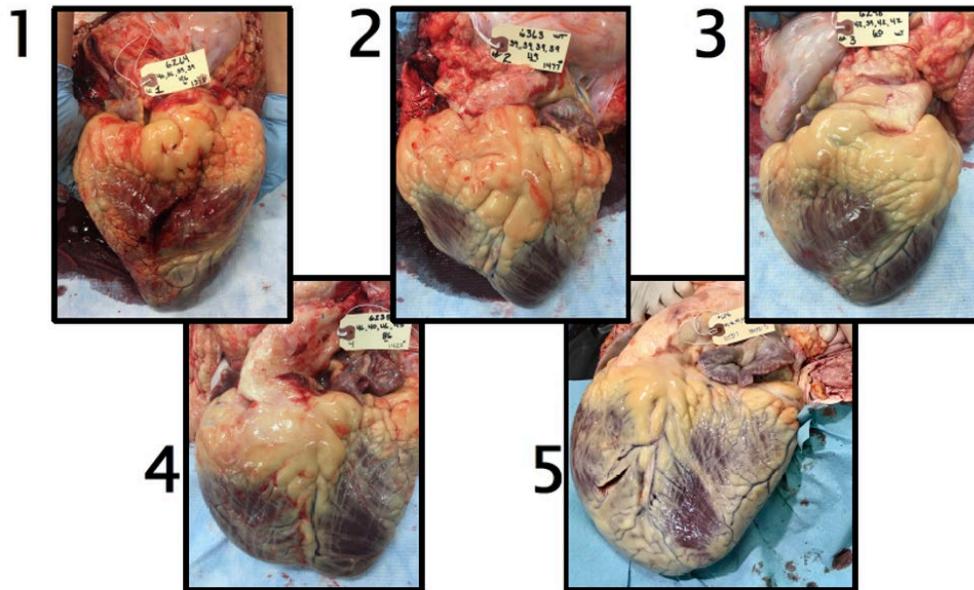
Over the last several decades, pulmonary hypertension has been increasingly reported in the feedlot industries (Neary et al., 2016), with increases in mortalities associated with pulmonary hypertension. The disease has increasingly been designated as Bovine Congestive Heart Failure, but it has also been known as "late term feedlot death". The incidence of this has resulted in increased mortality, often later in the feeding period when animal and feed costs have largely been incurred. Therefore, losses have a significant impact on overall profitability.

The increased reporting of BCHF has spurred research to better resolve a number of questions regarding this disease:

1. Does genetics play a role in BCHF?
2. Is the underlying pulmonary hypertension resulting in BCHF and HAD related, meaning are the 2 diseases genetically related?

However, one of the difficulties in developing a better understanding of BCHF has been the lack of a more robust approach to characterizing the disease beyond simply survival (or not). As such, Dr. Tim Holt of Colorado State University developed a scoring system (1 to 5; Figure 2) to quantify the level of cardiopulmonary remodeling occurring in the heart at harvest, with a score of 1 and 2 considered normal hearts and 3's showing signs of substantial remodeling, with the most severe being a heart score of 5. This system has been proposed to preclude the need to collect PAP scores on feedlot animals. Heart scores collected at harvest, when correlated with animal ID, pedigree, and genomic information, have laid the foundation for further investigation into the genetic component underlying the incidence of this disease.

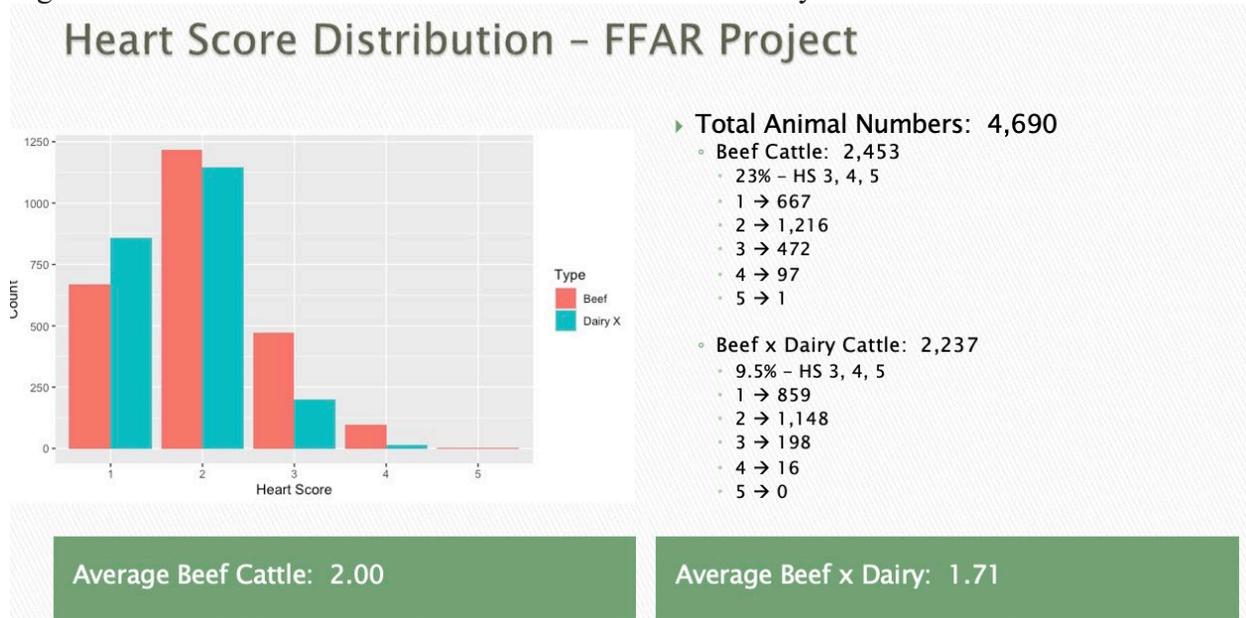
Figure 2: Quantifying heart remodeling through heart scores (Dr. Tim Holt)



Holt et al., as presented in
Heffernan et al., 2020

Using the heart scoring system, a project funded by the Foundation for Food and Agricultural Research's International Consortium for Antimicrobial Stewardship in Agriculture has furthered our knowledge of PAP and BCHF in moderate-elevation feedlots. This project evaluated both beef and beef-on-dairy cross cattle for heart score, with the distributions shown in Figure 3.

Figure 3. Heart score distributions from beef and beef-on-dairy fed animals at harvest.



The distributions for the 2 genetic types indicate that beef cattle appear to be more highly affected than beef-on-dairy cross calves in this study. As shown, animals with heart scores of 5 are relatively rare, and we hypothesize that most of these are feedlot mortalities. Additionally, in our experience, many animals with a heart score of 5 surviving to harvest often have their carcasses condemned. A subset of straight beef animals in this study had PAP scores taken at roughly 9 and 14 months of age, with the results indicating that pulmonary remodeling in cattle naïve to elevation, fed at roughly 3,500 feet of elevation, starts to experience cardiopulmonary remodeling at various levels of severity as observed through those PAP measures. This supports the occurrence of pulmonary hypertension in moderate-elevation feedlots, paralleling what is observed in high-elevation production systems.

Feedlot pulmonary hypertension appears to not only result in high elevation and feedlot mortalities, but indications are that even for animals reaching harvest performance is compromised, yet again, straight beef animals appear to be most affected, as shown in Table 1.

Table 1. Carcass performance in beef and beef-on-dairy fed animals by heart score.

Heart Score	Beef			Beef on Dairy		
	Carcass Wt (lb)	Marbling (score)	Ribeye Area (in ²)	Carcass Wt (lb)	Marbling (score)	Ribeye Area (in ²)
1	754.8	424	12.5	849.7	268	16.2
2	778.0	424	12.6	857.3	267	16.2
3	782.8	412	12.6	856.4	271	16.2
4	745.0	398	12.1	871.4	242	16.2

In straight beef animals, there is a reduction of about 22 lbs in carcass weight from the average of heart scores 1's and 2's to a heart score of 4. Using this same comparison, ribeye area shows a .4

in² reduction and a marbling score 26-point reduction. While beef from dairy animals shows the same differences in performance, there is a 17 lb increase in carcass weight, no change in ribeye area, and a 26 point reduction in marbling score. Except for the marbling score, where beef and beef on dairy animals appear to be subject to similar reductions, beef on dairy cattle does not seem to experience the same reductions in carcass weight and ribeye area.

GENETICS OF HEART SCORE

Initial analyses of heart score's heritability and relationship to PAP and other carcass performance traits are shown in Table 2. These results show that heart score has a heritability similar to that of PAP and, as such, should respond to selection. PAP measured in the feedlot and heart score are very highly genetically correlated, indicating that heart score information is indicative of pulmonary hypertension. Additionally, during the research to develop PAP EPD and better understand genetic contributions to BCHF, genomic profiles have been used to identify key markers of the diseases. Our indications are that both PAP and heart score are highly polygenic, meaning that many genes appear to influence both, with no single gene having an overriding effect.

Table 2. Heritability and genetic correlations of heart score, PAP, and carcass performance traits.

<i>Trait</i>	HS	PAP	HCW	BF	REA	Marb
HS	0.28 ± 0.10	0.94 ± 0.17	0.63 ± 0.20	0.15 ± 0.24	0.27 ± 0.22	0.07 ± 0.24
PAP		0.29 ± 0.16	0.66 ± 0.25	0.28 ± 0.29	0.15 ± 0.30	0.05 ± 0.30
HCW			0.61 ± 0.14	0.41 ± 0.16	0.51 ± 0.13	0.29 ± 0.18
BF				0.43 ± 0.13	-0.24 ± 0.19	0.35 ± 0.19
REA					0.60 ± 0.14	-0.17 ± 0.19
Marbling						0.45 ± 0.13

CONCLUSIONS

Both PAP and BCHF are conditions related to underlying pulmonary hypertension in beef animals. While the trigger for the development of HAD is the lower partial pressure of oxygen at high elevations, the trigger for BCHF remains in question. Despite a questionable cause of BCHF, research shows considerable genetic influence on both PAP and heart score, indicating both should respond to selection pressure aimed at genetic improvement. Additionally, records on the same individual indicate a strong genetic correlation between PAP on feedlot animals and subsequent heart score. Ongoing research is designed to evaluate the genetic relationship between high elevation PAP and moderate elevation heart score and will direct the development of selection approaches to reduce the overall incidence of pulmonary hypertension.

Finally, while the primary concerns of both diseases are associated mortality, increasing evidence indicates reductions in performance (especially carcass) are related to the degree of pulmonary hypertension as measured by heart score.

LITERATURE CITED

- Culbertson, M.M., M.G. Thomas, L.L. Leachman, R.M. Enns, and S.E. Speidel. 2017. Multivariate analysis of beef cattle pulmonary arterial pressures measured at differing elevations. *J. Anim. Sci.* 95(E. Suppl. 4):86.
- Glover, G. H., and I. E. Newsom. 1915. Brisket disease (dropsy of high altitude). *Colorado Agri. Exp. Sta.* 204:3-24.
- Heffernan, K.R., M.G. Thomas, R.M. Enns, and S.E. Speidel. 2020. Phenotypic relationships between heart score and feed efficiency, carcass, and pulmonary arterial pressure traits. *Transl. Anim. Sci.* 4(Suppl. 1):S103-107. doi:10.1093/tas/txaa114.
- Neary, J. M., B. K. Wildman, C. W. Booker, and P. S. Morley. 2016. Right-sided congestive heart failure in North American Feedlot cattle. *J. Vet. Intern. Med.* 30:326-334.
- Pauling, R. C., S. E. Speidel, M. G. Thomas, T. N. Holt, R. M. Enns. 2018. Evaluation of moderate to high elevation effects on pulmonary arterial pressure measures in Angus cattle. *J. Anim. Sci.* 96:3599-3605. doi:10.1093/jas/sky292.
- Speidel, S. E., M. G. Thomas, T. N. Holt and R. M. Enns. 2020. Evaluation of the sensitivity of pulmonary arterial pressure to elevation using a reaction norm model in Angus cattle. *J. Anim. Sci.* 98:1-9. doi:10.1093/jas/skaa129.

PULMONARY HYPERTENSION: NEW RESEARCH AND DEVELOPMENTS

Chase D. Markel
Department of Animal Sciences
University of Wyoming

INTRODUCTION

Bovine congestive heart failure (BCHF) is an increasingly recognized cause of morbidity and mortality in feedlot cattle across North America. The condition is thought to result from progressive bovine pulmonary hypertension (BPHT), which leads to right ventricular hypertrophy, reduced cardiopulmonary function, and ultimately heart failure. Although BCHF has traditionally been associated with high-altitude disease (HAD), it is now observed at a range of elevations, suggesting a complex interaction between genetic predisposition, environmental stressors, and production factors. Pulmonary arterial pressure (PAP) testing remains the gold standard for in vivo assessment of cardiopulmonary risk, but its use is limited in commercial settings due to cost and logistical constraints. Postmortem heart scoring (HS), a semi-quantitative method based on visual inspection of right heart morphology, is more widely used for phenotyping but suffers from subjectivity and limited scalability. To improve the quality and utility of these phenotypes, we present two complementary tools: an automated computer vision system for objective HS classification, and a composite PAP stability index designed to capture longitudinal changes in cardiopulmonary pressure. Together, these tools aim to improve phenotypic precision, support risk modeling, and enhance our understanding of BCHF pathophysiology in feedlot systems.

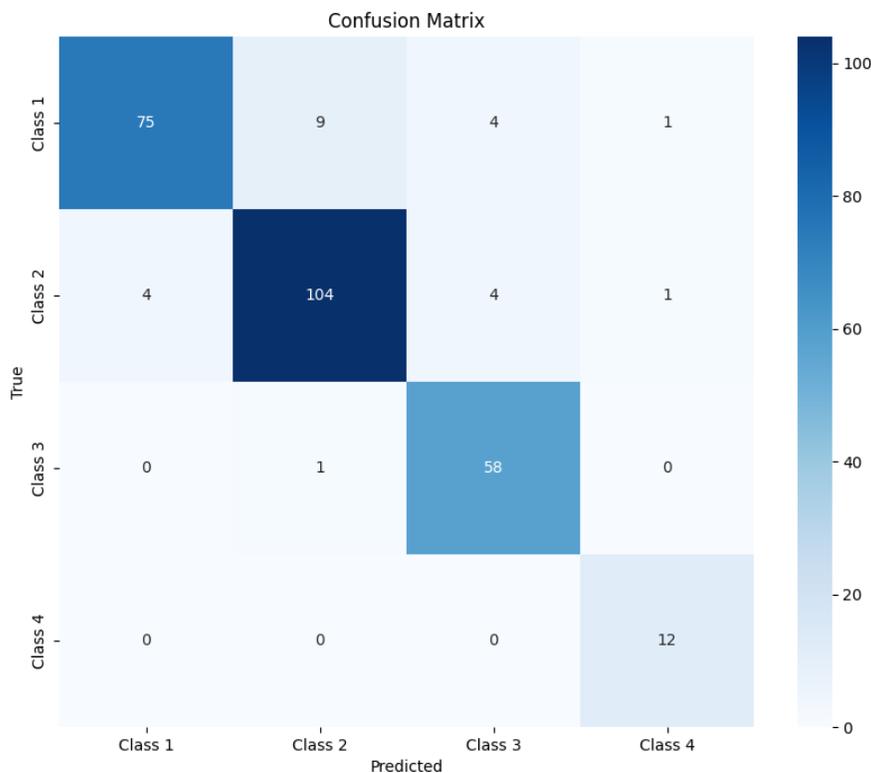
AUTOMATED PHENOTYPING OF BOVINE CARDIAC MORPHOLOGY USING COMPUTER VISION

Traceability of BPHT, particularly in cases of BCHF, has remained a persistent challenge since the early stages of epidemiological research on the condition. This difficulty is due in large part to the limitations of in-vivo diagnostics. Diagnosis of BPHT in live animals is often impractical in feedlot settings because the gold standard, PAP testing, requires expertise and repeated animal handling that are not feasible for routine use at scale. As a result, the most reliable phenotypic indicator for BCHF remains postmortem HS, a semi-quantitative classification based on gross morphological assessment of cardiac hypertrophy.

Heart scoring involves assigning a score from 1 to 5, where a score of 1 denotes a normal heart and a score of 5 indicates severe right ventricular hypertrophy consistent with advanced pulmonary hypertension. This approach is commonly used in genetic and epidemiological studies of BCHF due to its relative ease of application and strong correlation with disease severity. However, because the scoring process relies on human interpretation, it is subject to intra- and inter-observer variability, which can introduce error and reduce the consistency of large-scale data collection. To address this issue, we developed a computer vision model capable of automatically assigning heart scores from digital images of plucks (the heart and lungs, still connected, collected at slaughter).

The training dataset consisted of 862 beef pluck images collected from a commercial abattoir in northeastern Colorado. Each image was independently scored by trained human evaluators using the standard 1-to-5 HS scale. Images were standardized in resolution and subjected to extensive data augmentation (including rotations, scaling, and contrast adjustments) to enhance model robustness and generalizability. The data were split into training and testing sets using an 80/20 ratio. All preprocessing, model development, and evaluation were conducted in Python using the PyTorch deep learning framework (Paszke et al., 2019). We implemented a convolutional neural network based on the ResNet-18 architecture (He et al., 2016), initialized with pretrained ImageNet weights (IMAGENET1K_V1). The resulting model achieved a validation accuracy of 91.2% when evaluated on an independent set of 273 pluck images collected from a separate abattoir in central Nebraska.

Figure 1: Confusion matrix from independent validation of the automated heart scoring model.



This system provides a perfectly repeatable and scalable alternative to manual heart scoring. It is capable of evaluating thousands of carcasses daily without human intervention, enabling high-throughput phenotyping of BCHF across diverse regions. In addition to reducing subjective error, the ability to generate large phenotypic datasets from geographically distributed sources supports improved understanding of disease prevalence and lays the foundation for the development of predictive tools and genetic selection strategies aimed at reducing the incidence of BCHF in feedlot cattle.

ASSESSING LONGITUDINAL PULMONARY ARTERIAL PRESSURE RISK THROUGH COMPOSITE STABILITY INDEX

Pulmonary arterial pressure testing has long served as the primary method for assessing brisket disease risk in beef cattle, particularly for breeding animals intended for use at high elevations. Standard recommendations suggest measuring PAP at yearling age, after which animals are categorized into risk classes based on established thresholds (Holt and Callan, 2007). While this single timepoint approach is practical and widely used, it does not account for the dynamic nature of PAP, which has been shown to vary significantly in response to age, nutritional status, production stage, and other physiological or environmental factors. For example, unpublished data from multiple longitudinal studies show that PAP tends to increase in feedlot cattle or yearling bulls receiving a high plane of nutrition, with an average rise of approximately 0.10 mmHg per day. Conversely, replacement heifers transitioned from a high-energy diet to a maintenance ration can exhibit decreases in PAP, averaging around 0.03 mmHg per day. This variability complicates risk assessment, as an animal with an initial PAP of 42 mmHg, considered low risk, may cross into a high-risk category (>52 mmHg) within 100 days on feed, while others may experience pressure reductions under different management.

To better capture this temporal behavior, we developed a composite index that integrates both the baseline PAP value and its longitudinal trajectory. The index combines three biologically relevant components: the rate of change in PAP over time, the consistency of clinical risk classification, and the presence of persistently high PAP values. The rate of change is captured by a stability term that decreases as variability increases between two measurement points (Mean Stability). Zone stability assesses whether an animal remains in the same risk category (low, moderate, or high) across both timepoints, adding classification consistency beyond the raw values. A penalty is also applied to animals that maintain high-risk PAP levels (≥ 65 mmHg; this threshold can be adjusted based on population) over time, indicating persistent pulmonary hypertension. These components are weighted and summed to generate a final composite score that emphasizes animals with both favorable baseline PAP and stable cardiopulmonary performance.

$$\text{CompositeScore} = \omega_1 \cdot \text{MeanStability} + \omega_2 \cdot \text{ZoneStability} + \omega_3 \cdot \text{PersistentHighPAP}$$

This index offers a more refined and biologically grounded approach to brisket disease risk assessment and may serve as a valuable tool in research settings, particularly for genetic selection studies, elevation-specific deployment models, and the development of predictive algorithms aimed at reducing the incidence of bovine congestive heart failure. Its structure enables a more nuanced understanding of cardiopulmonary stability over time, providing insight that goes beyond single-point PAP measurements. However, because the index requires multiple longitudinal PAP readings, its implementation is likely impractical in most commercial production environments, where repeated measurements are cost-prohibitive, labor-intensive, and difficult to integrate into routine management. As such, the utility of this index may be best realized in controlled research contexts and as a foundational component in the design of more scalable risk management tools.

CONCLUSION

Pulmonary arterial pressure and postmortem HS remain the two most informative phenotypes available for investigating the onset and progression of HAD and BCHF. However, the utility of these phenotypes depends heavily on their precision, consistency, and biological relevance. The

tools presented in this work, automated heart scoring via computer vision and a longitudinally informed PAP stability index, represent meaningful advances toward improving phenotype quality and interpretability. These approaches reduce subjectivity, enhance throughput, and enable more robust comparisons across time and geography. While the technologies described may face limitations in large-scale, real-world implementation, particularly where repeated PAP measurements are required, they hold considerable value in research settings and as frameworks for the development of scalable risk assessment tools. Continued integration of novel technologies and more sophisticated analytical approaches will be essential to improving our understanding of BCHF and ultimately mitigating its impact on feedlot performance, carcass quality, and animal welfare.

LITERATURE CITED

- He, K., X. Zhang, S. Ren, and J. Sun. 2016. Deep residual learning for image recognition. Proc. IEEE Conf. Comput. Vis. Pattern Recognit. 770–778. doi:10.1109/CVPR.2016.90
- Holt, T. N., and R. J. Callan. 2007. Pulmonary arterial pressure testing for high mountain disease in cattle. Vet. Clin. North Am. Food Anim. Pract. 23:575–596. doi:10.1016/j.cvfa.2007.08.001
- Paszke, A., S. Gross, F. Massa, A. Lerer, J. Bradbury, G. Chanan, T. Killeen, Z. Lin, N. Gimelshein, L. Antiga, et al. 2019. PyTorch: An imperative style, high-performance deep learning library. Adv. Neural Inf. Process. Syst. 32. doi:10.48550/arXiv.1912.01703

USING VITRUAL FENCE TO IMPROVE GRAZING MANAGEMENT ON RANGELANDS

Mitchell Stephenson¹, Yijie Xiong², Mary Drewnoski², Elliot Dennis³, Hanifi Otgun³

¹ University of Nebraska – Lincoln (UNL) Panhandle Research, Extension, and Education Center

² UNL Department of Animal Science

³ UNL Department of Agriculture Economics

INTRODUCTION

The concept of using virtual fence (VF) for managing grazing patterns of cattle on rangelands has been researched since the early 2000s (Anderson 2006). The early prototypes in this research were expensive and not practical for application on large numbers of animals. However, the technology has now progressed to the point where application of VF at commercial scales has significantly expanded over the last 5 years in the United States. Currently, there are 4 companies that have developed VF products and provide VF platforms at commercial scales for cattle ranching in the United States; Vence (Merck animal Health), Eshepherd (Gallagher), NoFence (NoFence Grazing Technology), and Halter (Halter). Over the last 5 – 10 years, research across many organizations and universities has substantially increased and has evaluated many of the aspects of VF to determine its efficacy for grazing management, welfare to the grazing animal, and economics of incorporation at a ranch scale.

At its basic concept, VF is the use of a collar fitted around an animal's neck that has the capability to download user-defined fence boundaries and communicate the GPS location of the animal in real-time. Virtual fence technology uses audio and electric cues to signal (audio cue) to the animal when they are near the boundary and to deter (electric cue) the animal from crossing the boundary if they do not respond to the audio cue (Ehlert et al. 2024). A software platform provides an interface for producers to build fence boundaries, both spatially and temporally, on a computer, tablet, or mobile phone. The information is then transferred to the collar through either a cellular connection or a base station relay. As a result, livestock producers can develop intricate and infinitely flexible virtual boundaries to manage grazing livestock for defined rangeland management and livestock performance objectives. VF technology has the potential for enhanced opportunities to refine grazing management in ways that were previously impractical with physical fence because of cost and labor requirements.

EFFICACY OF VIRTUAL FENCE

Virtual fence can be highly effective at containing different classes of cattle within defined virtual boundaries, once cattle are trained to the audio and electric cues. In an Alberta, Canada study, heifers adapted to VF technology within 5-7 days and remained within VF boundaries more than 99% of the time (Harland et al. 2025). Boyd et al. (2022) evaluated the efficacy of VF to keep

cattle out of burned areas in the sagebrush steppe. In this study, the researchers found that with VF, cattle only incidentally crossed the VF boundary into burned areas and forage utilization on burned areas was less than 3% compared to 70% forage utilization a burned area without VF boundaries. Others have highlighted the efficacy of VF to exclude cattle from sensitive rangeland areas (e.g., riparian or critical habitat areas, Campbell et al. 2018, Murray et al. 2025) and the opportunity to implement rotational grazing strategies with VF on rangelands (Harland et al. 2025; Murray et al. 2025).

Another opportunity could be management of multiple groups of cattle in the same pasture or across larger rangeland landscape. Recent research conducted at the University of Nebraska – Lincoln Eastern Nebraska Research, Extension, and Education Center near Mead, NE found a high containment rate (>99%) when using virtual fence to control cattle in multiple groups in the same physically fenced pasture (Aguino et al. 2025). In addition, there were no differences observed in the number of cues that cattle received, suggesting that if cattle are properly trained and respond positively to the VF cues, there is a high probability that they will remain within the boundaries, even if other cattle are present in close proximity.

ANIMAL WELFARE WITH VIRTUAL FENCE

With the adoption of new precision livestock technologies, like virtual fence, it is important to consider the potential of acute (minutes to hours) and chronic (day to months) stress to the animal when shifting to this kind of management. Virtual fence systems rely on the animal's ability to positively associate the audio cue with the VF boundary and, thereby, reduce the negative consequence of receiving the electric cue. If VF increases cattle stress, and reduces the welfare of cattle grazing on rangelands, this could result in reduced livestock performance and health (Lee and Campbell 2021).

Recent research at the University of Nebraska – Lincoln used heart rate monitors (Polar Equine H10, Polar Electro) to assess acute stress of cattle when introduced to VF and after cattle had been trained to VF over the course of several months (Dozler et al. 2025). In this study, 20 cows were evaluated with and without virtual fence management in a 2.5 acre holding pasture. Heart rate measurements, movement, and behavior were all measured to assess the acute stress of VF audio and electric cues on cattle. Over 30-minute control and VF periods, HR response was not different. Increases in heart rate were short and generally observed for between 30 to 240 seconds following interactions with electric cueing events when compared to the established control period average heart rate (Figure 1). Movement of cattle tended to be greater during the VF period compared to the control. This was mostly associated with cattle exploring the pasture in the first 10 to 15 minutes of the VF period until they became more aware of where the VF boundaries were located. Observations generally showed cattle positively avoiding the VF electric cues within the 30-minute periods. After 60-days of grazing with VF on larger pastures, cattle received no difference in audio cues, but 66% fewer electric cues than the cattle's first interactions with the VF. This highlights the cattle's ability to learn to avoid the electric cues by turning away from the boundary when they received the audio cue. Overall, This study indicated VF cues caused relatively short and minimal acute stress to cows with calves and cattle learned to respond to audio cue warnings and avoid electric cues after being trained.

Other research has shown that cattle do not experience longer-term chronic stress with VF. In a study titled, “Heifers don’t care: no evidence of negative impact on animal welfare of growing heifers when using VF compared to physical fences for grazing”, Hamidi et al. (2022) reported no significant differences in live weight gain, herbage consumption or fecal cortisol metabolites over several weeks. Jeffus et al. (2025) and Ranches et al. (2025) also reported no differences in measured fecal, hair, or blood markers of stress hormones when cattle were exposed to VF management compared to physical fence over longer-time periods. Additionally, a number of studies have highlighted the ability of cattle to quickly adapt to management with VF, suggesting that cattle are capable of adjusting and positively responding to the audio and electric cues with minimal effect to animal welfare (Nyamuryekung et al. 2023, Ranches et al. 2025, Dozler et al. 2025). With this increasing amount of research, there appears to be strong evidence to support that VF does not cause longer-term, chronic welfare issues with cattle grazing on rangelands.

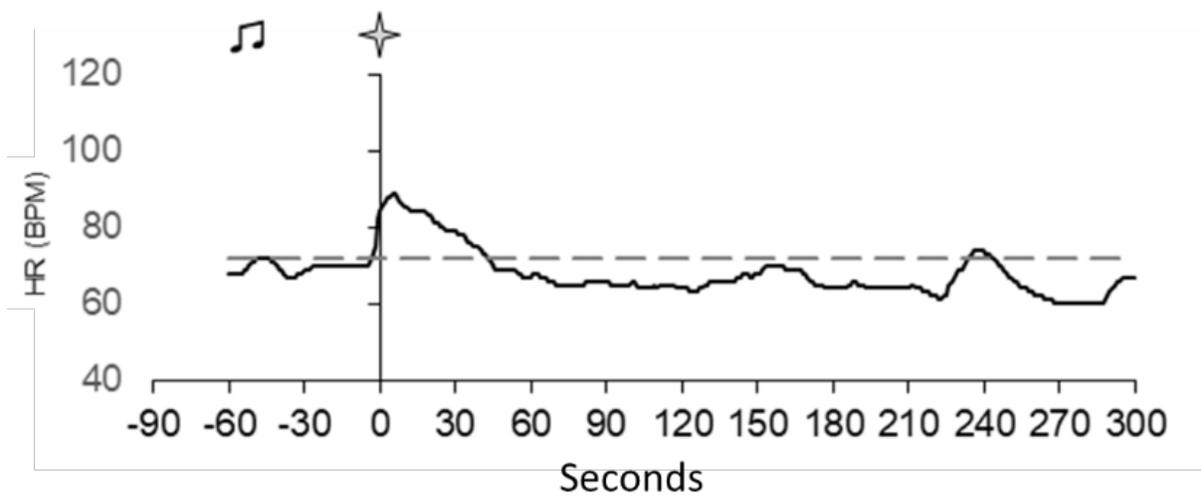


Figure 1. An example of the heart rate response (HR) of a cow following an audio (music note) and electric cue (0 second point). Dashed line represents the average heart rate during the 30-minute control period with no VF management (Adapted from Dozler et al. 2025).

ECONOMICS OF VIRTUAL FENCE

VF represents a significant capital investment, and producers considering adoption must weigh its upfront and annual costs against potential profit improvements. The economic decision to adopt VF technology hinges on its ability to generate returns that exceed those of conventional physical fencing, both electric and barbed wire. There are two primary sources of economic benefit from VF: the avoidance of costs associated with physical fencing and the creation of new operational efficiencies. Profitability of VF is most sensitive to the cost of conventional fencing, making it a critical factor in the economic calculation. However, models also demonstrate that these savings from avoided fence costs alone are not sufficient to make VF profitable. Therefore, achieving a positive return on investment requires producers to also realize tangible operational efficiencies.

These necessary operational efficiencies can be achieved through two main pathways: direct labor savings and indirect revenue enhancement. The first pathway, labor savings, is realized by reducing the time and expense required for tasks such as checking livestock, gathering and moving herds,

and repairing physical fences. The second pathway, revenue enhancement, comes from using VF as a precision grazing tool. By enabling producers to implement rotational grazing strategies and improved livestock grazing distribution with ease, the technology can potentially lead to improved forage utilization and potentially higher productivity from increased harvest efficiency. Some research has suggested that even modest productivity gains be enough to justify the cost of adoption.

Ultimately, a producer's decision should be based on a realistic assessment of their own operation. The key question is whether the combined benefits from avoided fence costs, labor savings, and potential productivity gains can offset the VF system's cost. It is also important to recognize that economies of scale play a critical role; the profitability of VF increases with herd size, as the large, fixed costs of infrastructure can be spread over more animal units. Therefore, producers should view VF not merely as a replacement for barbed wire or electric fences, but as a strategic investment in a precision management tool.

LITERATURE CITED

- Aquino, T., M. E. Drewnoski, B. Zhao, P. H. J. Fernandes, I. Vicci, M. Stephenson, Y. Xiong. 2025. Use of virtual fences to co-fence two groups of cattle with a shared virtual boundary. *Journal of Animal Science Supplement* 103:41-42.
- Anderson D. 2006. Virtual fencing - a concept into reality. Proceedings of the Conference of the Spatial Grazing Behavior Workshop CSIRO: Commonwealth Scientific and Industrial Research Organization; 61–91.
- Boyd, C.S., O'Connor, R., Ranches, J., Bohnert, D.W., Bates, J.D., Johnson, D.D., Davies, K.W., Parker, T., Doherty, K.E., 2022. Virtual fencing effectively excludes cattle from burned sagebrush steppe. *Rangeland Ecology & Management* 81:55–62.
- Campbell, D.L., Haynes, S.J., Lea, J.M., Farrer, W.J., Lee, C., 2018. Temporary exclusion of cattle from a riparian zone using virtual fencing technology. *Animals* 9 (1), 5.
- Dozler, K., Y. Xiong, T. Mulliniks, A. Little, M. Stephenson. 2025. Influence of virtual fence on heart rate response in beef cattle. *Rangelands* 47:72-83.
- Ehlert, K. A., J. Brennan, J. Beard, R. Reuter, H. Menedez, L. Vandermark, M. Stephenson, D. Hoag, P. Meiman, R. C. O'Connor, S. Noelle. 2024. What's in a name? Standardizing terminology for the enhancement of research, extension, and industry applications of virtual fence use on grazing livestock. *Rangeland Ecology and Management* 94:199-206.
- Hamidi, D., Grinnell, N.A., Komainda, M., Riesch, F., Horn, J., Ammer, S., Traulsen, I., Palme, R., Hamidi, M., Isselstein, J., 2022. Heifers don't care: no evidence of negative impact on animal welfare of growing heifers when using virtual fences compared to physical fences for grazing. *animal* 16, 100614 .
- Harland, A. J., F. J. Novais, C. J. Fitzsimmons, J. s. Church, G. M. ds Silva, M. C. Londono-Mendez, E. W. Bork. 2025. Evaluating virtual fencing as a tool to manage beef cattle for rotational grazing across multiple years. *Journal of Environmental Management* 381:125166.
- Jeffus, J., K. Wagner, L. Goodman, T. Parker, B. Wilson, A. Foote, R. Reuter. 2025. Virtual fences are not more stressful than conventional electric fences in rotationally stocked beef cattle. *Rangelands* 47:61-71.
- Lee, C.E., Campbell, D.L.M., 2021. A multi-disciplinary approach to assess the welfare impacts of a new virtual fencing technology. *Frontiers in Veterinary Science* 8, 637709.

- Murray B. R., K. L. Wagner, R. Reuter, L. E. Goodman. 2025. Use of virtual fencing to implement critical conservation practices. *Rangelands* 47:41-49.
- Nyamuryekung'e, S., Cox, A., Perea, A., Estell, R., Cibils, A.F., Holland, J.P., Waterhouse, T., Duff, G., Funk, M., McIntosh, M.M., Spiegel, S., Bestelmeyer, B., Utsumi, S., 2023. Behavioral adaptations of nursing brangus cows to virtual fencing: insights from a training deployment phase. *Animals* 13, 3558.
- Ranchers, J., C. Boyd, R. O'Connor, M. Ferreira, A. C. R. dos Santos, G. M. P. Hernandez, D. Johnson, D. Bohnert. Evaluation of blood markers of stress in beef cows during exposure to virtual fence stimuli. *Rangelands* 47:84-91.