Range Beef Cow Symposium XXVII

November 16 & 17, 2021

Rapid City, SD

Presented by Extension and the Animal Science Departments of:

South Dakota State University

Colorado State University

University of Wyoming

University of Nebraska - Lincoln

RANGE BEEF COW SYMPOSIUM

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November 16 – 17, 2021

Rapid City, South Dakota

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Beef Supply Chains and the Impact of the COVID-19 Pandemic[1]

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Introduction

One of many factors that make the U.S. cattle and beef industry an extremely complex set of markets is the disassembly of the beef animal into thousands of different products. These products are marketed in a vast array of final markets including retail grocery, food service and exports (Clark 2019). In the U.S., food expenditures prior to COVID-19 consisted of two, roughly equal market channels: food service, representing 54 percent of expenditures, and retail grocery, representing 46 percent of expenditures (USDA-ERS 2020). The unprecedented impacts of COVID-19 revealed to producers, processors and consumers, efficiencies as well as vulnerabilities of beef industry supply chains. The majority of COVID-19 impacts on beef product markets occurred in two different but overlapping waves beginning in mid-March 2020 with the majority of first-round impacts over by late-June. However, impacts in fed cattle markets and economic ripples have continued into 2021.

Beef packers provide the animal harvest and the primary fabrication of beef carcasses into wholesale products. Typically, packers fabricate several hundred basic wholesale products, which are marketed as several thousand products representing unique customer specifications. Subsequently, the majority of wholesale beef products move through a diverse and specialized set of further processing activities that further expand the set of products by several thousand additional products into largely separate supply chains. Following sections provide a brief overview of beef market sectors to better understand the impacts of COVID-19 on beef markets.

Retail Grocery Sector

Retail grocery is responsible for a large amount of beef sales and grocery sales are generally recognized as the main driver of total beef sales. Retail grocery typically sells a core set of products that is rather broad but also has considerable flexibility to adjust and feature different products when market conditions are favorable. Many supermarkets no longer have butchers or do any meat cutting in the store. Some independent stores and at least one major regional grocery chain are exceptions to this. The majority of supermarkets receive case-ready product from further processors, many of which are owned by major packing companies. Further processing for retail grocery involves cutting, packaging and labeling for retail, including ground beef retail packaging. Ground beef is discussed separately in more detail below. Retail grocery increasingly may include pre-marinated, ready to cook "meal kits" or similar value-added products. Retail grocery uses almost entirely fresh beef products

[1] This paper is adapted and expanded from Peel (2021).

with beef features following a standard calendar in which advertising and purchasing are planned several weeks to several months in advance.

Food Service Sector

Food service includes facilities sometimes referred to as HRI, meaning hotels, restaurants, and institutions (hospitals, schools, etc.). Restaurants represent a wide range of establishments including quick service restaurants (QSR or fast food), fast casual, cafeterias/buffets, casual dining, mid-level and fine dining. Individual restaurants or chains typically have limited and fixed beef product needs that are very specific and quite rigid. Collectively, restaurants utilize a wide range of beef products from ground beef to Prime steaks. The majority of food service beef products originate from further processing facilities in which products are aged, trimmed, sized for portions, tenderized, marinated or otherwise processed according to specifications. Food service further processing often produces additional beef products as primals and subprimals are further fabricated into multiple products including bench trim that is used for cooked ingredients in other processed products. Although most food service facilities use fresh beef products, some restaurants may utilize frozen portion-control steaks or other products that can be thawed on demand.

Ground Beef

Ground beef represents an estimated 45 percent of total U.S. beef consumption (Ishmael 2020) and plays a singular and uniquely important role in the U.S. beef industry in both retail grocery and food service sectors. Retail grocery establishments market large quantities of ground beef in a variety of forms and packaging. Ground beef for retail grocery is commonly part of supply chains that specialize in case ready products and processing specifically for grocery. For retail grocery, ground beef is typically made from fresh domestic meat products, frequently sourced from muscles and trimmings from specific primals as supermarkets often market ground beef with carcass references such as ground chuck, ground round, ground sirloin, etc.

Ground beef for food service is typically provided by specialized grinders that utilize a diverse set of inputs including fresh 50 percent (or similar) fatty trimmings, fresh lean trimmings or muscles from fed slaughter, fresh or frozen cow/bull lean trimmings and frozen imported lean trimmings. Margins are razor thin in food service, especially in QSRs that feature dollar menus, etc. and ground beef formulation is subject to intense cost scrutiny. Though there is some potential overlap in input sources for food service and retail grocery ground beef, the resources used for each tend to be largely separate.

Exports

Beef exports frequently originate with packers that produce export products according to unique specifications that are typically different from domestic products; or from exporting companies that may do additional fabrication/processing for export. Growing exports in recent years and expanded demand for specific products have significantly changed domestic markets. For example, various chuck products are popular in some Asian markets and have increased prices relative to other products and changed seasonal price patterns. Food service grinders, that can and have used these chuck items in ground beef now find that these products are effectively priced out of the ground beef market most of the time. Most exports are frozen and products are typically staged in cold storage prior to shipment.

Imports

The U.S. has long been a major beef importing country, despite being the largest beef producing country and a major beef exporter. Beef imports are driven by the demand for lean trim to support ground beef production with over 70 percent of imports estimated to be processing beef. It is estimated that imported lean trimmings accounts for over 25 percent of the total trim used for ground beef production in the U.S. Imported beef also includes some muscle cuts, primarily from Canada and Mexico. Beef trade with Canada includes some bilateral trade of similar products that are economically motivated by north-south transportation efficiencies (compared to east-west shipping in both countries). Beef imports from Mexico have grown dramatically in recent years and largely represent retail grocery and food service products targeted to Hispanic markets in the U.S.

COVID-19 Impacts

Food Service Shutdown

The first wave of impacts, which began in mid-March of 2020, resulted from the near total shutdown of food service. Abruptly, food demand at retail grocery nearly doubled. The surge in retail grocery demand was further aggravated by panic buying as consumers attempted to stockpile food at home. Retail grocery demand quickly overwhelmed the retail grocery supply chain resulting in localized and temporary shortages in retail stores. It is important to recognize that there was no actual shortage of product during the first month of the shutdown, but rather bottlenecks in the supply chains. Figure 1 shows beef production was above year earlier levels until April. It became quickly apparent that food service and retail grocery supply chains are very specialized and as a result somewhat inflexible. Food service processors are not equipped to package and label products for case-ready retail sale; and in many cases, distribution systems are largely separate.

The shutdown affected various beef products differently according to their primary use. Table 1 shows that the initial impact was price decreases for products heavily used in food service, e.g. tenderloin (IMPS 189A)[2], brisket (IMPS 120A) and ribeye (IMPS 112A). Simultaneously, products used at retail, especially products that support retail ground beef, i.e. chuck and round products (IMPS 114A, 116A, 168, 170) saw immediate price increases (Table 1). Over a period of weeks, adjustments eventually allowed some food service processors, distributors and retailers to adapt to retail grocery demand. Creative solutions included some restaurants, experiencing no, or greatly reduced, foot traffic, selling raw product direct to consumers, either from existing inventories when the shutdown occurred, or because they still had access to food service supply chains. Quick service restaurants (QSR) recovered somewhat quicker than full-service restaurants because of the availability of drive-

[2] Specific beef product references are identified by the corresponding Institutional Meat Purchase Specification (IMPS) product code. IMPS codes are maintained by the Agricultural Marketing Service (USDA-AMS) and are available at https://www.ams.usda.gov/sites/default/files/media/IMPS100SeriesDraft2020.pdf.

thru service, which further reduced some of the retail grocery burden. Full-service restaurants developed or emphasized take-out, curbside and delivery options, often with a limited menu. Adjustments to the limited food service channel continued through April and May and, to some extent, for many weeks thereafter. As of late 2021, many restaurants are still operating with limited menus and limited hours due to changes in the business environment and continuing pandemic impacts along with severe labor shortages.

The contrasting impacts in retail grocery and food service ground beef supply chains is demonstrated in Figure 2, which shows weekly prices for chucks (IMPS 113C) and fresh 50 percent trimmings. In the first few weeks after the shutdown of food service, markets for ground beef sources showed diverging price impacts. From early March to early April, the price of beef chuck clods (IMPS 114A) and chuck rolls (IMPS116A) increased sharply, driven by sharply higher retail grocery demand for ground beef (Table 1). Simultaneously, the price of 50 percent lean trimmings, used primarily for food service ground beef, decreased nearly 39 percent, to 18-year lows. After another four weeks or so, arbitrage and adjustments re-established the normal price relationships between these beef product markets. Most beef wholesale markets increased to record levels in April and May (Table 1) due to the supply disruptions in beef packing, although tenderloin (IMPS 189A) did not reach record high levels because the product is heavily dependent on food service demand, which remained severely reduced.

Packing Plant Disruptions

The second wave of initial pandemic impacts began in April 2020 when COVID-19 affected the labor force of harvest and processing installations and severely reduced output. Never have so many packing and processing plants been affected simultaneously by reductions in capacity. Some harvesting plants completely shut down for up to two weeks and others curtailed output due to labor force reductions. Cattle slaughter decreased weekly through the month of April, reaching a peak reduction of 34.8 percent down year over year the end of April, and then slowly recovered through May. Total beef production over a nine-week period of these effects was down 17.9 percent compared to the same period one year earlier (Figure 1). This reduction in beef production resulted in real, though temporary, shortages of product that looked to many consumers like more of the same conditions as the initial shutdown in March and early April. The beef supply disruptions were exaggerated by the continuing limitations in the food service sector and the added demand continued to stress the retail grocery supply chain. Over several weeks, additional adjustments were made to help food service supply chains support retail grocery including more bulk packaging and, in some cases, temporary exemptions from some labeling requirements.

Retail beef prices, which reflect retail grocery prices (as opposed to food service), responded as expected but with some difference in timing. The monthly retail all-fresh beef price increased modestly in April before spiking higher in May and June. The May all-fresh price jumped to $704.50/cwt., up 18.7 percent over the January and February average pre-COVID level of $593.60/cwt. and 19.3 percent higher year over year. The all-fresh retail price peaked in June at $738.20/cwt., up 26.2 percent compared to June 2019 levels. Retail beef prices decreased in July and August, albeit more slowly than wholesale beef prices, and remained higher year over year in August. An important market function is to use higher prices to ration demand when supplies are limited and thus avoid shortages. In this situation, the dramatic rise in retail beef prices helped to ration limited beef supplies in the March to May period but the magnitude of the shock and supply disruptions overwhelmed rising prices and led to temporary, sporadic product shortages in retail grocery.

The impact on and perception of consumers to these two waves of impacts was similar due to the lack of product in grocery stores in both cases. The reality of those impacts was very different - one due to bottlenecks and rigidities in the supply chain and the other the result of actual reductions in product availability. The combined impacts of the shutdown and packing plant disruptions was unprecedented volatility in beef product markets which has continued in 2021 with continuing COVID-19 impacts and the ongoing recovery of food service markets.

Beef exports also dropped sharply in May and June before recovering in July and by August exceeded year earlier levels. Beef imports spiked higher with a delay, jumping sharply in July and remaining well above year earlier levels in August. Beef imports increased in the summer in response to strong ground beef demand from the recovery of QSR restaurants. Large supplies of fatty trimmings resulting from heavy carcass weight in domestic fed cattle and stimulated additional lean demand.

2020 Fed Cattle Markets

The reductions in packing plant operations effectively cleaved beef product markets from cattle markets for several weeks. During this period, beef product markets generally moved in opposite directions from fed cattle markets. The lack of packing capacity created beef shortages that led to immediate and dramatic price spikes for beef products while that same lack of packing capacity created an immediate excess supply of fed cattle relative to packer demand and led to lower fed cattle prices.

Reduced cattle slaughter in April and May, 2020 resulted in a marketing backlog of fed cattle that took many weeks over the summer and fall to work through. No cattle were depopulated and delayed feedlot marketings resulted in excess supplies of fed cattle that pushed fed cattle price lower into July before recovering into the fall. Delayed fed cattle slaughter resulted in heavier carcass weights, higher quality grading percentages and other lingering impacts on beef supplies and product mixes.

Many concerns were voiced about the disconnect between fed cattle markets and boxed beef cutout prices when there was, in fact, an unavoidable temporary physical disconnect that caused prices to move in opposite directions above and below the packing level of the industry. Although this was an extremely unusual situation, the market reactions at all levels were exactly what is expected and helped support a remarkably rapid recovery in beef product markets.

The Role of Cold Storage

The beef production disruptions and product shortages resulting from COVID-19 provoked questions about the availability and use of beef in cold storage to supplement fresh beef supplies. Most beef marketed in food service and retail grocery is fresh and moves to final consumption in a matter of a few days to a few weeks at most. Cold storage inventories are frozen stocks of products held more than 30 days and does not typically consist of a complete set of beef products. Beef in cold storage includes products staging for export, which are mostly frozen and imported beef products (also frozen) until they are used. Cold storage beef supplies typically increase in the fall and winter and include supplies of domestic lean trimmings resulting from seasonally higher cow culling in the fall of the year. These lean trimming are used to support ground beef production for seasonal grilling demand the following summer. Occasionally, unique market situations result in commercial firms putting other products into cold storage. This is not a regular or preferred practice as cold storage adds cost and frozen beef is often marketed at a discount to fresh product.

In 2020, beef in cold storage increased counter-seasonally in March before declining seasonally in April and May, likely as a result of the abrupt loss of food service demand. Cold storage was not available to offset retail grocery product shortages because it consists of the wrong set of products and because the quantity of cold storage holding is small. Monthly beef cold storage inventories averaged 458 million pounds in 2019. This represents less than one week of beef production, which averaged over 513 million pounds per week in 2019. This means that even if all cold storage beef was pulled out at once, it would represent less than one week of beef supply and, as noted previously, would not match the mix of products needed in food service and retail grocery markets.

Cattle and Beef Markets in 2021

Impacts on Fed Cattle Markets

The biggest direct impact of the 2020 COVID-19 impacts in 2021 was on fed cattle markets. While the initial marketing backlog occupied fed cattle markets for much of the remainder of 2020, the feedlot placement dynamics carried over into 2021. In 2020, feedlot placements were delayed in March and April, followed by higher placements in June through September. These delayed placements resulted in a bulge in feedlot inventories and market ready fed cattle in 2021. By itself, this placement backlog would not have caused major problems, but the beef packing industry faces capacity constraints that are the result of long-term downsizing of the packing industry combined with chronic labor challenges (aggravated by continuing COVID-19 impacts). The result, through much of 2021, has again been a physical disconnect between the demand for beef products and the demand for fed cattle. With limited packing capacity, the supply of fed cattle has exceeded packing demand and held fed cattle prices down relative to beef markets. Declining cattle numbers will eventually drop feedlot production below this constraint and reconnect cattle and beef markets.

Wholesale and retail beef prices have risen sharply in 2021, partly the result of ripple effects from last year and ongoing pandemic impacts. However, the bigger drivers this year are strong domestic and export demand combined with declining beef production late in 2021.

Recovery and Permanent Impacts?

As noted previously, the majority of the initial COVID-19 shocks were resolved by the end of June, 2020. Certainly, there were continuing impacts after June and additional recovery has continued in 2021. Ripple effects on beef quality, product mixes, beef exports and imports, and feedlot dynamics have extended well beyond 2020. Food service is still significantly diminished with a slow recovery that will last many more months.

Many questions have been raised about likely permanent or very long-lasting effects of CVOID-19 on food industries, beef supply chains, and the cattle industry. Given the on-going nature of the situation, it is premature to say anything definitive about permanent impacts. There are clear indications of several changes that will affect food industries; including the likely loss of food service establishments (which may rebuild or be replaced over time); changes in travel, especially business travel in a world of Zoom meetings; a larger role for take-out, drive-thru, and home delivery food service; and the extent to which home food preparation results in long-term reduction in food service demand. Only time will provide the perspective to understand the types of changes and long-term impacts on food industries.

COVID-19 also exposed rigidities and lack of agility of beef supply chains to respond to this type of shock. Questions have been raised about the likelihood of fundamental changes to increase the resilience of beef supply chains. Certainly, it seems likely that individual firms may assess some business practices and make some changes. Firms may consider a wider range of procurement practices, such as contracts and other means to enhance both supply reliability and manage price risk. Many firms may devote additional resources to management planning with such things as supply chain mapping and other activities that will help identify supply chain redundancies and contingency plans to reduce the impact of future supply shocks (Norwood and Peel, 2020). However, the current structure of food service and retail grocery supply chains evolved in response to efficiencies and economic returns to specialized facilities and have contributed to reducing the cost of food in the U.S. Less specialized multi-function facilities that operate simultaneously in food service and retail grocery chains would be less efficient and more costly. Marginal changes in management and operational flexibility to increase the tactical agility of firms are more likely than massive reinvestment in new beef supply chain infrastructure.

Summary

COVID-19 has revealed both strengths and weaknesses in beef supply chains. It has also revealed much about market economics. Under normal, stable market conditions, markets coordinate resource and product allocation with such efficiency and subtly as to be largely unrecognized. Only in the face of abrupt and unexpected shocks are the reactions of markets to rebalance and restore equilibrium revealed. Freely operating markets react with dramatic, sometimes surprising and confusing responses to massive and unprecedented shock such as COVID-19. Consumers, producers, companies and policymakers all learned much about how beef supply chains and the market-based economy works as a result of COVID-19.

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Table 1. Wholesale Beef Price Changes, Selected Products.

	Product	IMPS*	Shutdown Impacts	Reduced Production Impacts
			% Price Change 3/6/20 – 4/10/20	% Price Change 4/10/20-5/8/20
1	Ribeye	112A	-17.1	+80.9
2	Chuck Clod	114A	+27.1	+150.7
3	Chuck Roll	116A	+39.1	+67.9
4	Brisket	120A	-15.5	+105.5
5	Inside Round	168	+28.4	+106.2
6	Gooseneck Round	170	+31.1	+90.6
7	Loin Strip	180	+17.8	+50.7
8	Loin Top Butt	184	-2.1	+129.0
9	Tenderloin	189A	-42.0	+126.2
10	Fresh 50s	Trim	--38.9	+720.0

Data sources USDA AMS LM_XB 459 and LM_XB 460, compiled by the Livestock Marketing Information Center.
*Institutional Meat Purchase Specifications

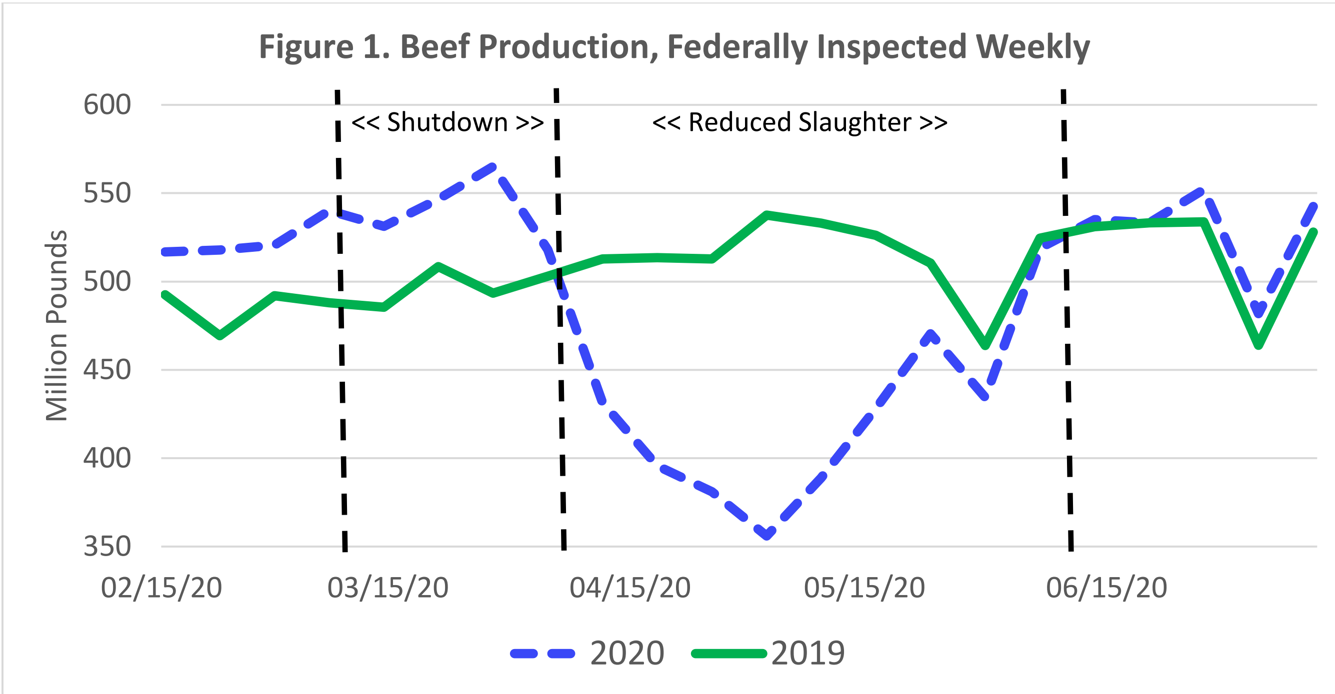
Figure 1. Beef Production, Federally Inspected Weekly
600
550
500
450
400
350
Million Pounds
<< Shutdown >>
<< Reduced Slaughter >>
02/15/20
03/15/20
04/15/20
05/15/20
06/15/20
2020
2019

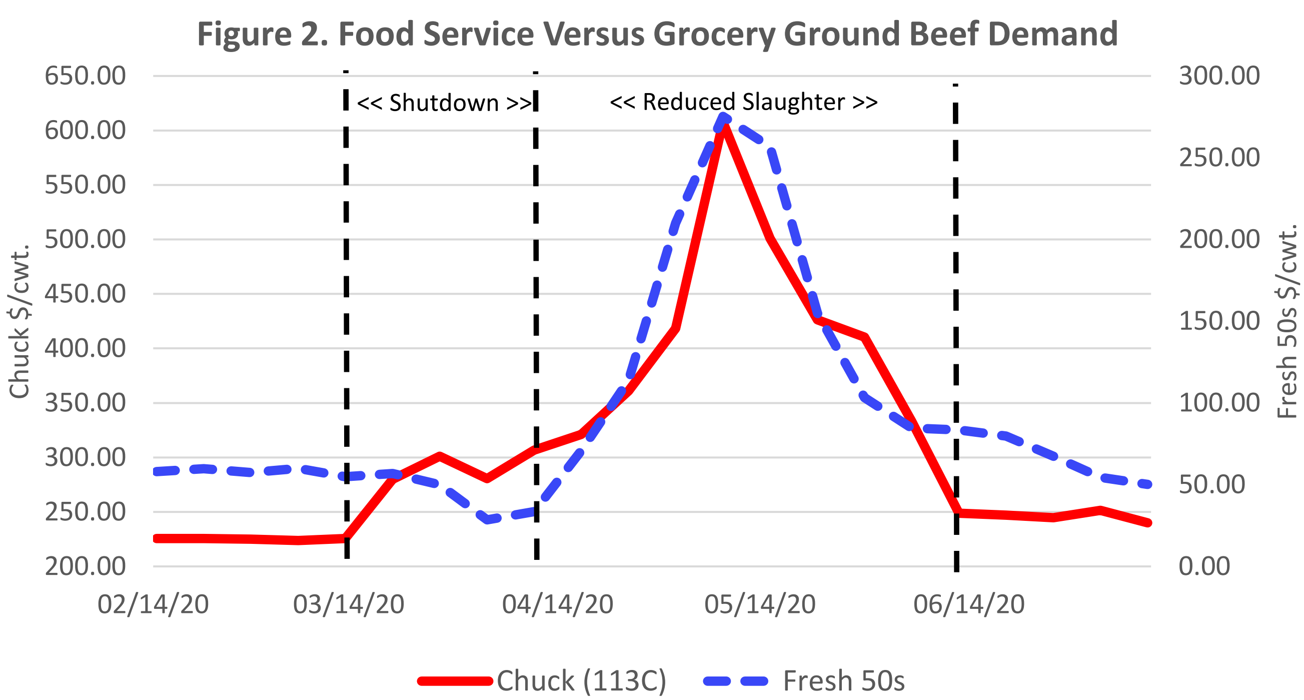
Figure 2. Food Service Versus Grocery Ground Beef Demand
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
250.00
200.00
Chuck $/cwt.
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Fresh 50s $/cwt.
<< Shutdown >>
<< Reduced Slaughter >>
02/14/20
03/14/20
04/14/20
05/14/20
06/14/20
Chuck (113C)
Fresh 50s

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Trends in Red Meat Consumption[1] and Retail Demand

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INTRODUCTION

Although red meat, particularly lean red meat, has been well established as a nutrient dense food that provides high-quality protein consisting of multiple essential nutrients in the diet, controversy still exists regarding the role of red meat in chronic disease outcomes. Recommendations to decrease intake of foods contributing to total dietary fat and saturated fat have often suggested reducing red meat consumption. Several current organizations providing online dietary suggestions about recommended daily or weekly protein intake suggest limiting or reducing consumption of red meat. However, these general recommendations to limit or reduce red meat often do not reference how much red meat is currently being consumed in the U.S. or what the level of reduction that should occur to follow.

ESTIMATING DIETARY INTAKE

Three methods are primarily utilized to assess the amount and quality of foods in human diets. These include 1) dietary recalls, 2) food disappearance data, and 3) food frequency questionnaires (Gifford et al., 2017). Dietary recalls rely on an individuals' memory of all dietary intake in a 24-hour period by probing for as much detail as possible. One of the most robust dietary intake datasets that is available in the U.S. utilizes a dietary recall method obtained from the National Health and Nutrition Examination Survey (NHANES). Trained interviewers use an Automated Multiple Pass Method to ask individuals to recall as much detail as possible about all foods and beverages consumed in the previous 24 hours on two separate days. The dietary intake portion of this survey is used to estimate the quantity of foods consumed and the nutrient contribution to the diet. The NHANES survey is nationally representative and reports large, comprehensive datasets every two years.

The U.S. Department of Agriculture Economic Research Service (USDA-ERS) estimates food availability, which is commonly referred to as food disappearance data, to infer consumption trends of several foods that are tracked from production through retail (USDA-ERS, 2021). These data from USDA-ERS also include loss-adjustments to account for food spoilage, plate waste and other losses. These food availability or disappearance data are presented as per capita availability, which is based on the amount of a food product available to the U.S. population. The USDA-ERS provides total pounds of food available annually and as per capita food availability to reflect daily amounts of certain food groups available to the U.S. population.

Food frequency questionnaires are used to assess longer dietary trends. This method can often be used by nutrition researchers conducting epidemiological studies that are interested in estimating long-term usual intake of broad food categories over time (Shim et al., 2014). However, the level of detail that this method is designed to capture can be problematic for researchers to interpret. Additionally, limitations of the two previous methods also exist. Limitations of these methods must be considered when evaluating the quantity and quality of foods consumed by individuals.

DIETARY GUIDANCE

Several sources of dietary guidance exist for the public to access in the U.S. The Dietary Guidelines for Americans (DGA) is a joint publication between the U.S. Department of Agriculture and U.S. Department of Health and Human Services released every five years since 1980. The DGA is the result of a national group of scientists that evaluate the scientific body of literature in order to compile the most relevant set of dietary recommendations for individuals, dietitians, the medical and health care profession and researchers to access. The 2015-2020 and 2020-2025 DGA both highlighted the importance of following a healthy dietary pattern at every stage of life to support healthy lifestyles. Within the healthy dietary patterns that include lean meat as part of the pattern, recommended amounts in the form of ounce equivalents per week are outlined as a subgroup of total protein on a daily and weekly basis (USDA & USHHS, 2020). The suggested weekly intake ranges of meats, poultry and eggs as a subgroup of total protein foods in the Healthy-Mediterranean Style Eating Pattern and in the Healthy U.S. Style Eating Pattern from the most recent release of the DGA is provided in Table 1.

Table 1. Daily Calorie Level and Weekly Recommended Protein Sub-group Amount of Meats, Poultry and Eggs outlined in both the Healthy-Mediterranean Style Eating Pattern and Healthy U.S. Style Eating Pattern in the 2020 Dietary Guidelines for Americans[1].

Daily Calorie Target in Dietary Patterns (kcal)	Subgroup of Meats, Poultry and Eggs Level (ounce equivalents/week)
1,000	10
1,200	14
1,400	19
1,600	23
1,800	23
2,000	26
2,200	28
2,400	31
2,600	31
2,800	33
3,000	33
3,200	33

[1]Overview from Appendix 3 of the 2020-2025 Dietary Guidelines for Americans (USDA & USHHS, 2020).

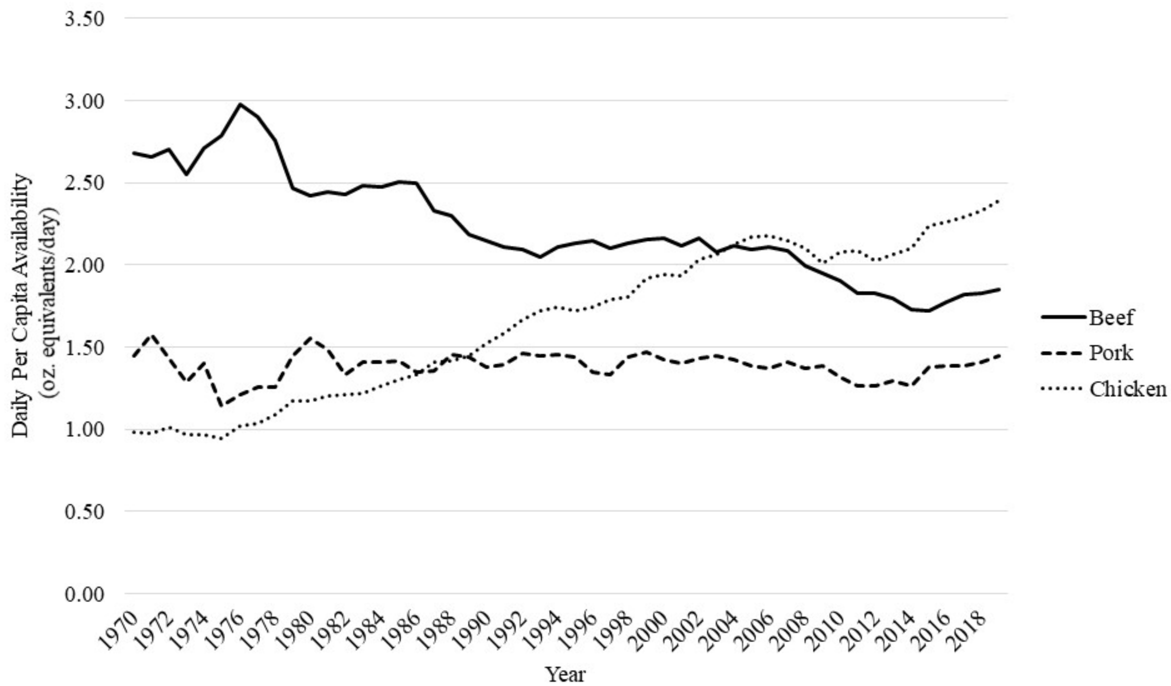
Several other organizations have provided resources and dietary guidance publicly available for individuals to reference. Organizations that have directly addressed red meat as part of these recommendations are provided below.

- The World Cancer Research Fund suggests limiting red meat consumption to 12–18-ounce equivalents per week (WCRF/AICR, 2018).
- The American Heart Association (AHA) suggests consuming no more than 5.5 ounces of fish (prepared without frying), shellfish, skinless cooked poultry and trimmed lean meats per day (AHA, 2017).
- The 2019 American College of Cardiology/American Heart Association recommends minimizing red meat in the diet (Arnett et al., 2019).
- The World Health Organization suggests limiting total energy intake from fat to less than 30% and saturated fat limited to less than 10% saturated fat. To meet these targets, meat along with other animal foods, palm oil and coconut oil are called out as sources of saturated fat (WHO, 2021).
- The American Cancer Society describes a healthy eating pattern as one that limits or does not include red and processed meats (Rock et al., 2020).
- The American Diabetes Association recommends limiting red meat as a source of saturated fat in the diet (ADA, 2021).

OVERVIEW OF RED MEAT CONSUMPTION IN THE U.S.

Since some dietary recommendations suggest target levels of red meat in the diet or suggest reducing or limiting consumption of red meat, questions have arisen about what the current consumption levels in the U.S. population are in order to better understand if suggested intake of red meat align with dietary guidance. The USDA-ERS daily loss-adjusted per capita availability (USDA-ERS, 2021) and the 2015-2016 NHANES dietary datasets (USDA-ARS, 2021a) were used to assess recent red meat consumption levels. Loss-adjusted per capita food availability data provided by the USDA-ERS were utilized to infer consumption of red meat and evaluate trends of consumption over time in the U.S. population. Specifically, daily availability of beef, pork and chicken available at retail between 1970 and 2018 were plotted in Figure 1. Loss-adjusted per capita availability ounce equivalents per day estimates of beef, pork and chicken in 2019 compared to 1970 changed by -30.8 % (beef), 0.3% (pork) and 143.9% (chicken). A total estimate of 3.3-ounce equivalents per day of total red meat (sum of beef, pork, lamb, and veal) was reported in the USDA-ERS dataset (USDA-ERS, 2021) on a loss-adjusted per capita basis. These loss-adjusted availability data provide an overview of changes in food availability at retail for meat products on a species and per capita loss-adjustment basis to infer consumption in the U.S.

Figure 1. Trend of per capita loss-adjusted[1] daily ounce equivalent availability of beef, pork and chicken between 1970 and 2019 in the U.S.



[1]Data from the United States Department of Agriculture, Economic Research Service, Food Availability (Per Capita) Data System, Loss-Adjusted Food Availability, Meat, poultry, fish, eggs, and nuts (USDA-ERS, 2021).

As mentioned previously, the dietary intake data from the NHANES dataset collected every two years are one of the most comprehensive dietary intake datasets available. While the trends observed in the USDA-ERS datasets provide valuable inferred consumption, the dietary recall methodology used to collect dietary intake data in the NHANES survey, although not without limitations, provides a greater level of detail about foods and beverages consumed among a nationally representative sample of individuals throughout the U.S. every two years. Dietary intake data available from the 2015-2016 National Health and Nutrition Examination Survey compiled into the Food Pattern Equivalency Datasets (NHANES, FPED) were utilized to assess consumption of ‘meat’ (USDA-ARS, 2020). The NHANES, FPED dataset (USDA-ARS, 2021a) compiles records of individual foods from participants on each of the two interview or survey days into food quantity (i.e., ounce-equivalents) within broader categories of food groups. For example, the ‘meat’ category includes the quantity of ounce-equivalents of beef, veal, pork, lamb and game meat (organ and cured meats are categorized separately) that was consumed among the individuals surveyed in the NHANES dataset.

A total of 9,544 individuals were included in the 2015-2016 NHANES dataset, but 5,017 of these individuals were considered adults aged 20 years or older that participated in providing dietary intake information on Day 1 of the dietary portion of the NHANES dataset.

Of this group of adults, 4,204 individuals provided dietary intake information on a second, subsequent day. Table 2 includes the number and percentage of adults on the first and second dietary recall days that consumed various amounts of ‘meat’.

Table 2. Number and percentage of adults[1] participants consuming meat at various levels as categorized in the 2015-2016 National Health and Nutrition Examination Survey, Food Patterns Equivalents Database[2].

Meat[3] Intake (ounce equivalents each day)	Day 1 Dietary Recall	Day 2 Dietary Recall
	n (%)	
	(*n*=5,017)	(*n*=4,204)
≤1 oz.	2,911 (58.0%)	2,657 (63.2%)
≤2 oz.	3,491 (69.6%)	3,094 (73.6%)
≤3 oz.	4,029 (80.3%)	3,482 (82.8%)
>10 oz.	76 (1.5%)	54 (1.3%)

[1]Adults were considered individuals in the 2015-2016 National Health and Nutrition Examination Survey 20 years of age or older at the time of dietary recall.
[2]Adapted from the 2015-2016 National Health and Nutrition Examination Survey, Food Patterns Equivalents Database Available at: https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/fped-overview/ (USDA-ARS, 2021a).
[3]’Meat’ refers to beef, veal, pork lamb, game meat, but excludes organ and cured meats.

Of the complete group of adults that provided dietary intake information on the first survey day, 58.0% of these adults consumed ≤1 ounces. of ‘meat’ and nearly 70% of adults consumed ≤2 ounces of ‘meat’ on Day 1 of the survey. Since a single whole serving of cooked red meat is typically based on a 3-ounce equivalent (approximately 85 grams), ≤3 oz. was used to estimate the percentage of adults in the survey that consumed this level of red meat on Day 1. Approximately 80% of adults consumed 3-ounce equivalents or less and about 20% of adults consumed greater portions of ‘meat’ on Day 1 of the dietary portion of the 2015-2016 NHANES survey. A small percentage of adults (1.5%) consumed the greatest amounts of ‘meat’ in a single day.

The average intake of ‘meat’ among adults on Day 1 in the 2015-2016 NHANES, FPED dataset was 1.62-ounce equivalents. In general, the average ‘meat’ intake among adults in this dataset was comprised of 34.6% beef items, 17.0% pork items, 15.9% of ‘meat’ in the form of ground beef or a burger (i.e., uncured meat portion of a hamburger, cheeseburger or bacon cheeseburger) and 32.5% of other food items falling under the ‘meat’ category (USDA-ARS, 2021b).

CONSIDERATIONS OF CURRENT CONSUMPTION AND RETAIL DEMAND

Lusk et al. (2021) highlighted the market disruptions and impacts throughout the beef and pork industries throughout the COVID-19 pandemic. One implication of market disruptions throughout the COVID-19 pandemic included a shift towards alternative sources during severely impacted time points. However, Lusk et al. (2021) also pointed out that there is a limit to the magnitude of state-inspected plants, custom-exempt plants and on-site/on-farm slaughter as alternative outlets. Additional impacts to meat prices and estimated consumption of red meat have been summarized across the meat industry at the retail level during the COVID-19 pandemic. An overview from the Power of Meat 2021 report (available online from the North American Meat Institute; NAMI, 2021) highlighted a few trends in 2020:

- Although disruptions occurred at specific time points of the pandemic, meat dollar sales increased by 19% in 2020.
- During 2020, 43% purchased more meat than before the pandemic.
- More than 80% of meals were prepared at home in April (89%) and December (84%).
- About 3 out of 4 individuals agreed that meat should belong in a healthy and balanced diet.

These trends suggest that meat has remained a priority in U.S. households in 2020. Further research is needed to clarify how pre-COVID-19 and ongoing-COVID-19 red meat consumption levels compare, such as accounting for any sources of food spoilage or plate waste at home between sales data and consumption data. Future data regarding consumption of red meat will be of interest to researchers to assess changes in consumption among the U.S. population once it is processed and publicly available from NHANES or other data sources.

CONCLUSIONS

The role of red meat on the impacts of chronic disease outcomes will likely a focus of human nutrition and medical research efforts. Evaluating current levels of red meat consumption across the U.S. population and assessing consumption trends over time will continue to be essential to nutrition researchers. Estimated unprocessed red meat or 'meat' intake from the FPED and WWEIA portions of the 2015-2016 NHANES suggests that the majority of the U.S. population is consuming 3 oz. or less. It appears that approximately 20% of the U.S. population may be consuming more than a serving of cooked meat daily and a small percentage of individuals are consuming the highest levels of meat daily. Additionally, trends of food availability at retail suggest that beef intake has decreased over the past few decades. Bias among NHANES participants, underestimated dietary intake reporting, how frequently consumption of red meat aligns with meeting dietary pattern targets, and accuracy of the type and amount of food availability estimates could all be limitations that challenge estimates of red meat consumption in the U.S. Further research is certainly needed to identify methods that address limitations of these dietary intake methods and provide current levels of red meat intake, particularly as trends of red meat consumption during COVID-19 and currently are evaluated further.

ACKNOWLEDGEMENT

[1]Part of this overview summarizes data and information from research that was funded by The Beef Checkoff. The author of this proceedings was the principle investigator for this funded research.

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DIRECT MARKETING BEEF: MANAGEMENT CONSIDERATIONS FOR ENHANCING CARCASS QUALITY AND CUTABILITY

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INTRODUCTION

Consumer interest in purchasing beef directly from farmers and ranchers has been trending upwards in recent years. A variety of factors may lead a consumer to purchase directly from a producer. They may have an interest in purchasing local, a desire to know the source of their protein, or an interest in a specific quality or credence attribute (grass finished, exceptional marbling, specific breed, organic, etc.). However, when purchasing beef directly most consumers expect an eating experience that would be as good or better than buying beef from retail. Individual preferences will ultimately dictate a consumer's decision regarding which beef to purchase. To gain customers and market share, it is important to know what you are producing and be able to consistently provide a quality product. It is also critical to be able to accurately communicate the attributes of your product and explain the traits that may differentiate it from others in the market, thus creating demand. Raising beef cattle for a successful direct marketing program requires specific management considerations, an understanding of meat processing regulations, an appreciation for factors that influence carcass yield, and knowledge of traits that influence palatability and consumer satisfaction. Direct marketing enterprises can also be enhanced by good communication, aptly managing customer expectations, and providing excellent customer service.

MANAGEMENT CONSIDERATIONS

One of the first considerations for direct marketing beef is where to feed the cattle. Cow-calf producers interested in direct marketing may not have adequate facilities or feed resources to feed and finish cattle on their own operation. One option is to work with a local feedyard or nearby producer with cattle feeding knowledge and resources. Paying feed and yardage to finish cattle at another location allows producers to retain ownership of their cattle and oversee marketing decisions without the potential need to develop facilities, acquire feed resources, or have the knowledge and skills to feed finishing diets with high levels of grain. However, finding a custom feeder that can accommodate the number of cattle a producer would like to finish (whether it's a few head or a pen full) and fits their management and marketing needs is key. If a custom finisher is not available or if a producer desires to manage cattle throughout the finishing period on their own, they should consider how their facilities align with their management and marketing goals. The type of feed resources (grain- or forage-finishing), number of animals to finish, and time of year cattle are finished will determine the land and facilities needed.

General Facility Needs

Customers interested in purchasing directly from a producer may make their purchasing decision based on the perception of how they believe cattle should be raised. For example, providing shade and windbreaks could provide the dual benefit of improving animal performance and offering a market benefit. Similarly, selecting a feeding location that is well-drained to avoid muddy conditions and considering the addition of bedding to drylot pens can improve animal comfort and performance, as well as consumer perception.

Producers interested in finishing cattle should have handling facilities that are capable of handling cattle with minimal stress and safely restraining cattle up to the desired finished weight. Consideration should be given to possible points of injury to cattle such as protrusions that could cause bruising to finished animals resulting in product loss. Use of a scale is highly recommended. Weighing animals at the beginning of the feeding period will help target desired feed intake and final weight. Weighing cattle periodically during the feeding period can allow monitoring of animal performance to ensure cattle are meeting targeted rates of gain. A final weight can also be useful in determining if intended weight endpoints are met and determining sale price, but care should be taken weighing finished cattle to avoid bruising just before harvest. Access to feed on a consistent basis is critical to maintain performance. Adequate bunk space is necessary to ensure all animals have access and that competition is not an issue between animals of different sizes. Designated areas for feed storage should be planned to keep feed clean, dry and minimize pests.

Animal Selection

The adage “begin with the end in mind” is a good one to follow when producing beef for a direct marketing program. Producers should consider their end-product goals when selecting animals to finish. The majority of consumers desire beef that is flavorful, juicy, and tender. One of the most common selection criteria to achieve high quality beef is selecting animals with the genetic potential to marble. Marbling is the common name for intramuscular fat, which is fat deposited within muscle. Marbling is positively correlated with beef flavor, juiciness, and tenderness (Savell and Cross, 1988; Garmyn et al., 2011; O’Quinn et al., 2012) In general, as marbling increases the likelihood of a positive eating experience also increases. Dairy breeds such as Jersey are known for exceptional eating quality (Arnett et al., 2012) and Japanese Wagyu cattle are known for exceptional marbling (Gotoh et al., 2014), however they generally take longer to finish and have reduced cutability (lower yields) compared to conventional beef breeds (Arnett et al., 2012; Gotoh et al., 2014). In contrast large-framed, heavy muscled beef breeds are higher yielding, but often lack the potential to deposit adequate levels of marbling. If your aim is to produce cattle with acceptable marbling, there is flexibility to the breed composition, but it is important to select cattle with the genetic potential to deposit marbling. Cattle that are moderate-framed and early maturing with adequate muscling and marbling potential are ideal for many direct marketing programs.

Tenderness is another attribute related to consumer satisfaction and is a trait that can be influenced both before and after harvest (Warner et al., 2021). Producers should consider pre-slaughter factors that can influence tenderness including animal age, breed, and sex. Older animals tend to producer tougher, darker colored meat that is less desirable for whole muscle cuts such as steaks (Weston et al., 2002). While there can be a market for older animals for use in ground beef, it is not recommended to market older cows or bulls for traditional steaks and roasts due to potential issues with toughness. Additionally, cattle with Brahman influence are known to produce tougher meat due to an increase in calpastatin, which is a protein that inhibits the aging process (Warner et al., 2021).

While most American consumers prefer the taste of grain-finished beef that is tender and highly marbled, that isn't the case for everyone. There are consumers that desire extremely lean beef with little marbling, others that prefer the flavor of grass finished beef, or others that may desire a non-tangible attribute such as an environmental practice employed on your operation. Selecting cattle that will consistently achieve your end-product goals in the desired time frame is a critical decision that will impact profitability of the direct marketing enterprise as well as customer satisfaction.

Finishing Programs

With high demand for the services of small processors, producers are often scheduling harvest appointments one to two years in advance for cattle that may not even been born yet. In the current market, it is very difficult to procure a harvest appointment on short notice, which highlights the importance of coupling proper cattle selection and nutritional management to optimize direct marketing opportunities. A good nutrition program is one of the most significant aspects of producing a high-quality carcass. A wide range of ingredients can be utilized to formulate rations to grow and finish cattle, and these diets will vary in energy and protein density resulting in different rates of gain.

Typically, with a grain-based finishing ration a growing phase is recommended that emphasizes skeletal and muscle development, and a finishing phase for enhanced marbling deposition and fattening. Regardless of the ration being used, it is important to make changes to amount and ingredient composition gradually to allow adaptation by microbes in the rumen and avoid digestive issues such as acidosis and bloat (Harty and Rusche, 2021a). If finishing cattle on a high concentrate diet (80-90% concentrate) it is important to include roughage (10-20%) to maximize rumen and microbial health. Cattle thrive on routine and feeding twice a day at the same time every day can help maximize performance and avoid digestive issues (Harty and Rusche, 2021b). Ionophores can help maximize feed efficiency and minimize digestive disorders; however, inclusion may not fit with some customers perception of "natural". Grain-finishing can require 80 – 200+ days on feed to meet harvest endpoints depending on the energy of the ration, age, weight, and health of the cattle, and genetic potential for growth. In grass-finishing systems, providing high quality grass via grazing or harvested forage is necessary to maintain growth. Supplementation may be necessary at different times of the year to maintain growth. If supplementation with grain is used this should be communicated to customers to ensure their expectations are met. Grass-finished beef generally takes longer to reach their endpoint and cattle may be 18-28 mo of age at harvest (Capper et al., 2012). The key to any finishing program is to keep cattle growing efficiently using balanced feed rations. Given the variety of feedstuffs available and specific needs of each operation consulting a nutritionist or University Extension beef specialist to help design and balance rations is highly recommended.

The type of finishing ration utilized can impact animal performance as well as palatability. While there is room for both grass- and grain-finished beef in the beef marketplace it is important to understand and accurately represent your product. It's important to note that the typical U.S. beef consumer is accustomed to the flavor profile and palatability attributes of grain-finished beef (Van Elswyk and McNeill, 2014). Beef from grass-finished animals may be identified as having a grassy flavor and can have a different cooking aroma compared with grain-finished beef. Also, consumers may note a difference in the visual appearance as the fat of grass-finished beef can be more yellow in color and the lean tissue can be darker (Crouse et al., 1984; Leheska et al., 2008). Grass-finished beef is also generally finished at a lighter weight than grain-finished beef and, as a result, are often leaner with less marbling (Leheska et al., 2008; Van Elswyk and McNeill, 2014).

Health and Growth Promotants

Customers may inquire about the use of antibiotics or growth promoting implants. This information should be shared as appropriate without disparaging others who chose to use or not use these technologies. Herd health programs generally involve prevention of disease through vaccination protocols and control of internal and external parasites. When animals become sick and antibiotics are used as appropriate to restore health, they can be marketed after the appropriate withdrawal time, but they should not carry an antibiotic-free claim. While it may be tempting to try and capture value from a sick or poor doing animal by selling it as freezer beef, it should be noted that animals that have been sick and treated multiple times can produce lower quality carcasses (reduced marbling score) (Holland et al., 2010).

Proper use of hormone implants to improve growth rate allows for cattle to be finished earlier thereby requiring less time on feed and fewer resources per pound of meat produced (Johnson et al., 2013; Webb et al., 2020). However, the implant strategy, potency, and timing should be considered to ensure they are meeting your growth promotant goals without detrimental impacts on marbling and tenderness. A nutritionist, pharmaceutical representative, or University Extension feedlot specialist can be consulted to meet these goals for your specific operation. The resource savings created by using implants could be promoted to consumers that are environmentally conscious. Conversely, if you are seeking to market beef raised without added hormones, avoidance of these technologies can also be promoted. With all animal health products and technologies, it is critical to follow the label instructions on slaughter withdrawal time and it is recommended that all producers adhere to the Beef Quality Assurance guidelines for administration of these products.

DETERMINING ENDPOINTS and AVOIDING CARCASS DEFECTS

Market readiness

Evaluation of market readiness is a skill that improves with experience. Typically, cattle grow skeletal and muscle mass until they near a mature frame and reach their muscle growth potential. Marbling has been shown to be continuously deposited throughout growth, given that the animal is on an adequate plane of nutrition, whereas subcutaneous fat deposition increases substantially once skeletal and muscle growth potential has been met. Assessment of subcutaneous fat is one means of determining market readiness. Fat is deposited from anterior (front) to posterior (rear) of the animal, so it is important to observe how fat deposition has progressed for timely marketing. Common points to observe are fat fill in the brisket area, fat cover over the back (particularly over the 12^{th} and 13^{th} ribs), fat accumulation on either side of the tailhead, as well as in the udder or cod area of heifers and steers, respectively. Cattle vary widely in their weight at market endpoint; however, it is common for grain-finished cattle to weight 1200-1450 pounds at harvest and grass-finished cattle to weigh 1000-1200 pounds.

The desired 12th rib fat thickness for marketing beef has traditionally been in the range of 0.4 - 0.5 inches, however with current genetics and larger carcass weights it is not uncommon to see grain-finished cattle with 0.6 - 0.8 inches of backfat. Grass-finished cattle will typically finish with less backfat (0.2 – 0.4 inches). Evaluation of actual hot carcass weight is also important to assessing market readiness. Typical beef carcass weight should range from 650-950 pounds, depending on sex, feeding program, and cattle type. However, customer preference may influence your decision to harvest at a leaner or fatter level. It is recommended to evaluate the actual carcass by measuring fat thickness at the 12th rib, ribeye area, and marbling score. These measurements will determine the level of finish, muscle size, and marbling that was actually achieved. This data can help with future decisions regarding animal selection and market timing (a University Extension meat science specialist can be consulted to train or assist with these measurements).

Influence of Stress in Finished Cattle

Cattle producers have long appreciated the connection between proper animal care and the health and productivity of their herds. Producers involved in directly marketing beef should adhere to best management practices with the goal of consistently producing a quality end-product that meets consumer demands. Using low-stress handling techniques on finished cattle that are close to slaughter is especially impactful to beef quality because they reduce stress, and stress is a major contributor to several quality defects in cattle (Grandin, 2020).

Dark Cutters

Dark cutting beef is the result of a prolonged stress such as mixing animals, fighting, feed deprivation, drastic changes in ambient temperature, chronic illness, heifers in heat or any combination of events that deplete muscle glycogen prior to slaughter (Scanga et al., 1997; Grandin, 2020). Glycogen is the storage form of glucose and serves as an energy reserve to fuel muscle contraction. Stressors cause the release of hormones such as epinephrine that function to break down muscle glycogen as an immediate source of energy. If glycogen stores are exhausted at the point of slaughter muscle does not progress through the normal conversion of muscle to meat. Instead, the lack of glycogen leads to lower-than-normal lactic acid production resulting in a limited pH decline and a product characterized by extremely dark colored lean tissue, high water-holding capacity, limited shelf-life and a sticky texture. In addition, dark cutting beef is highly variable when analyzed for tenderness, one of the most important beef quality attributes (Wulf et al, 2002).

Bruising

Bruising is caused when a blow or impact ruptures the small blood vessels under the skin. A bruise could be caused by a stick or stone, animal horn, metal projection from holding or working facilities, or animal fall and could happen anytime during transport, handling or holding prior to slaughter. Stress during these events can increase excitability and the chances of bruising. Normally a bruise will resolve when the underlying blood is degraded and clears from the area. However, if a bruise occurs close to the time of slaughter and the body is not able to heal from the event the bruise will be present on the carcass. Bruised areas of the carcass are trimmed away, and that tissue is condemned therefore contributing to a reduction in total meat yield and carcass value (Grandin, 2017, Harris et al., 2017).

Blood splash

Blood splash is a condition that occurs when small blood vessels located in muscle rupture allowing blood to leak into the surrounding tissue. This blood then appears in the meat as a dark red spot and is visually undesirable. Stress can elevate blood pressure and contribute to the incidence of blood splash in beef cattle (Meat Technology Update, 2006; Grandin, 2020).

CARCASS PROCESSING and PRODUCT CONSIDERATIONS

Inspection Regulations

When cattle are ready for harvest, farmers and ranchers must choose a locker facility to take their animals to for processing. In a direct marketing system, cattle are typically harvested at small, local butcher shops. Depending on the customer base and business goals, cattle producers have three meat inspection options to have their beef processed: custom exempt, state inspection, and federal inspection.

Custom Exempt

Custom exempt processing facilities are very common in rural areas. These facilities provide slaughter and processing services and return the meat to the owners of the animal. The meat that is processed by custom exempt facilities is for in-home use by the owner, their household, and their non-paying guests. The meat produced at these facilities must be labeled "Not For Sale" and may not be sold by the owner or donated. Cattle producers can still deliver cattle to custom exempt facilities; however, at the point of slaughter, the animal must be owned by the individual(s) who will be taking the meat home. This means that the consumer will pay the producer for the live animal and the processor for the slaughter and processing services.

State or Federal Inspection

Cattle producers intending to direct market retail cuts to consumers need to have their animals processed at state or federally inspected facilities. South Dakota and Wyoming operate state meat inspection programs while Colorado and Nebraska only operate under USDA inspection. The requirements of state inspection programs are that they are at least "equal to" the rigor of federal inspection. The largest difference between state and federal inspection is that state inspected meat can only be sold within state lines while federally inspected meat can be sold in interstate commerce and be exported.

Product consistency

One of the most important factors for customers to become repeat customers is consistency of product. While no cattle producer can guarantee that every animal will produce meat with the exact same eating experience, there are live animal and carcass management decisions that can help improve consistency.

Tenderness

As mentioned earlier, younger animals generally produce more tender meat than older animals. Because of this, it is important for tenderness consistency to slaughter animals at roughly the same age every time. Another factor that impacts tenderness of meat is postmortem aging (also referred to as hang time). Research has shown that considerable improvements in tenderness can be observed until 14 - 21 days of aging (additional improvements can be made after that point but they are not as noticeable).

Flavor

Meat flavor can be impacted by a variety of factors. One of the most influential factors is animal diet, specifically finishing diet. Animals from a grain finishing system produce meat that has a different flavor than animals from a forage finishing system. While neither system results in unacceptable meat quality or flavor, consumers tend to have a strong preference for one flavor over the other. On the carcass side, aging method (wet or dry) has one of the strongest impacts on flavor. Dry aging can be done on a whole carcass or on primal cuts and is accomplished by leaving the meat exposed to the air in the cooler. Wet aging is done on primal or retail cuts and is done by vacuum sealing the meat and leaving it in refrigerated conditions. Dry aging tends to impart a more intense beef flavor than wet aging.

Yield Expectations

A very common question meat science Extension specialists receive is "I only received 500 pounds of beef back from a 1200 pound steer. Did the locker steal my meat?" The answer to that questions is "probably not". Individuals buying bulk beef can expect 30 to 50 percent retail cut yield from an animal's live weight (Wulf, 1999). Where exactly an animal's retail cut yield will fall depends on dressing percentage and cutting yield.

Dressing Percentage

Dressing percentage is the percentage of live weight that makes up the carcass. Average beef animals have a dressing percentage of about 63% while dairy steers yield about 59%. This number can be impacted by a variety of factors including gut fill, muscling, fatness, hide cleanliness, and breed characteristics. The influence each of these factors has on dressing percentage depends on if the weight contributed by each factor stays with the carcass or not. For instance, animals with more fat or muscling have increased dressing percentages compared to leaner or lighter muscled animals because muscle and fat stay on the carcass. If an animal has a lot of gut fill or mud stuck to their hide, the dressing percentage will be decreased because that weight does not stay with the carcass. Dairy or dairy influenced animals tend to have lower dressing percentages because they generally have larger heads and longer (heavier) legs that do not remain with the carcass.

Cutting Yield

The cutting yield is the percentage of the carcass that ends up packaged for the consumer and is influenced by the cutting specifications set by the consumer as well as carcass composition. Carcasses that are leaner and heavier muscled will have an increased cutting yield than fatter, lighter muscled carcasses. This is because most retail cuts are trimmed to 1/8 to 1/4 inches of subcutaneous fat (also known as back fat). Fatter carcasses require more trimming than leaner carcasses. Another factor that determines cutting yield is whether the cuts are made boneless or left bone-in. Bone-in products such as T-bone steaks or bone-in chuck roasts will weigh more than their boneless counter parts and increase the yield of the carcass. Another factor that affects cutting yield is the fat content of ground product. A common ground beef blend is 80% lean and 20% fat. However, if the consumer desires leaner ground product the overall yield will decrease as more fat is removed from the packaged product. The final factor that impacts cutting yield is the skill of the butcher. The more experience a butcher has cutting certain cuts of beef, the better they are at maximizing the yield of that cut. The producer should keep this in mind if they are asking the butcher to fabricate different cuts than what are normally offered as it could negatively impact the cutting yield. Many custom processors fabricate beef carcasses using a band saw and may not be willing or able to cut boneless steaks and roasts. If boneless cuts are important to the business model or customers, the producer should make sure the meat processor is willing to make them before scheduling animals for slaughter.

Carcass Cutout

A beef side can be fabricated into eight primal regions: chuck, rib, loin, round, flank, plate, brisket, and shank. The chuck and the round are the largest primals in the carcass, collectively making up ~50% of the weight of the side (Holland, et al., 2014). Except for steaks such as the flat iron, chuck eye, and eye of round, these two primals are primarily cut into roasts, stew meat, and ground beef. The rib and the loin make up the "middle meats" and provide the well-known steaks such as the ribeye, T-bone, New York strip, and filet mignon. However, these primals only make up ~27% of the carcass. This concept can be difficult to grasp for a customer who is new to buying beef in bulk and was expecting to get all of their product back as steaks. The flank, brisket, plate, and shank comprise the remaining 25% of the carcass, yield few retail cuts, and are predominately used for ground beef.

Cutting Instructions

Providing cutting instructions is potential area producers can enhance customer service by providing education on carcass breakdown and approximate amounts of each type of cut to expect. This information can be requested from most University Extension meat science specialists, or producers can work directly with their butcher to create a personalized cut list. It may also be beneficial to include recommended cutting and packaging information; including steak thickness and quantity per package, the weight of ground beef per package, or the desired weight of roasts. It is also important to convey to the consumer that some popular cuts may not be available if others are chosen. For example, if they want T-bone steaks, they will not get New York strips and filet mignon because they are cut from the same muscles; T-bones are just the bone-in version. The same is true for bone in chuck or arm roasts and flat iron or Denver cut steaks. Another concept that may surprise consumers is the size of a bone-in sirloin steak. While the average consumer is used to boneless baseball sized sirloin steaks, custom butchers commonly cut sirloin steaks that include all sirloin muscles and produce steaks that can feed two to three people.

Freezer Space

Once the meat is cut, packaged, and frozen, the consumer must then store it in their home freezer. The space needed for storage is dependent on both the yield of the animal, the types of cuts that were ordered, and how the meat was packaged. An average beef animal with a 1200 pound live weight could produce approximately 500 pounds of retail cuts. A consumer who purchased a quarter of beef from this animal will likely need 4.5 to 5.5 cubic feet of freezer space (University of Minnesota, 2020). Large cuts such as a whole brisket and ground beef stuffed in chubs will require more space to store than smaller roasts and steaks and ground beef packaged in bricks simply because of stacking efficiency.

IMPLICATIONS

Addition of a direct marketing enterprise has the potential to increase income of a cattle operation and allows producers to have control over animal quality, nutrition, management, and health throughout the finishing period. Producers should consider the attributes that differentiate their product and seek ways to consistently produce beef that meets their customer's demands. Consumers generally desire flavorful, juicy, tender beef with a bright cherry red color. To meet this expectation, it is recommended to market beef that is healthy, young, and has been on an appropriate finishing ration. Direct marketing also requires cattle producers to be knowledgeable salesmen and provide guidance to their customers on processing decisions, so they have a better idea of what to expect from the final product.

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Blockchain in the beef industry, Profit for steak

Steve Lupien
University of Wyoming

NOTES

What should you be asking your seedstock producer about your bull?

David Schuler
Schuler Red Angus

NOTES

Proceedings, The Range Beef Cow Symposium XXVII
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Adding Yearlings to the Cow-Calf Enterprise for Drought Mitigation or Income Diversification

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Introduction

Incorporating yearling cattle into a cow-calf operation can be a drought mitigation tool or a way to provide income diversification for cow-calf producers. While some producers have integrated farming and ranching operations, or are in close proximity to those who do, other producers' resources may be limited to pasture grass, what hay the operation can produce, and a limited budget for supplemental protein. An operation may find purchasing and transporting crop residues or hay, silage, and other commodities to maintain a cowherd with limited perennial grass is cost prohibitive. This makes income diversification difficult and can force the cow-calf herd into liquidation during severe drought.

Cow depreciation is the second largest expense for a cowherd after feed costs. When young cows have to be liquidated, it is very costly to the operation. Although cow depreciation can be more complex than this, cow depreciation is defined as purchase or development cost minus cull price divided by the number of productive years. Therefore, if a cow was purchased or developed for $2000 and sold as a cull cow for $800 after only 3 calves, her depreciation cost to the ranch is $400. ((2000-800)/3). Cow depreciation is often overlooked as it is not an expense the producer writes a check for, but it is a real cost to the operation all the same. Cow depreciation exists with or without a drought situation, but with drought cull prices are often depressed as many producers are selling cows, which increases supply, and cows are often thin due to lack of grass, reducing their value further.

Diversifying the operation with yearling cattle allows producers to liquidate cattle that were going to be sold in the fall sooner if necessary, without liquidating cows from the core herd to save grass resources. If the yearling averages 850 pounds (0.85 AUM) (AUM being animal unit month) and the cow-calf pair averages 1700 pounds (1.7 AUM), then 2 yearlings can replace one cow-calf pair (Forero et al., 1989). Reducing the number of pairs and replacing them with yearlings can give producers income diversification as well as drought mitigation flexibility.

Stocker Cattle Options

When producers consider incorporating a yearling operation into a cow-calf operation, they should consider the forage, labor, facilities, and equipment resources, the cattle genetics of the ranch, as well as marketing options when making a decision.

Steers. Retaining steer calves may be a viable option for some ranching operations. Steers ready for feedlot entry after summer grazing can be profitable and management decisions will depend largely on marketing times and options (Folmer et al., 2005; Merical et al., 2021).

Heifers. Retaining heifers can provide the operation with additional marketing flexibility. Heifers selected for maternal traits could be marketed as bred heifers in the fall after summer grazing while their open counterparts could be marketed for feedlot entry along with heifers who did not meet breeding criteria earlier in the summer. Developing a plan for supplementation and grazing of the weaned heifer is an important step in the success of breeding heifers the following summer. Providing an adequate plane of nutrition and meeting metabolizable protein needs of the weaned heifer prior to summer grazing have been shown to increase pregnancy rate and overall longevity in the cowherd (Beck et al., 2005; Mulliniks et al. 2013; Speer at al. 2021). In these studies, daily gain of the wintering heifers was averaging around 1.0 lb/d. Freetly et al. (2001) observed that winter management of replacement heifers could be variable as long as heifers are growing and meet minimal BW requirements before mating.

Custom grazing yearlings. Producers may find that leasing out the grass to someone else who owns yearlings is a good fit for their operation. Negotiated price should take into consideration which party provides care, salt, mineral, or supplementation for the cattle, maintenance of the pastures and wells, as well as an acceptable death loss. A written agreement should be signed by each party, which includes start and end dates for grazing, as well as a clause that allows the land owner to terminate grazing early due to drought, fire, or other natural disasters.

Supplementation Options

Winter supplementation. The decision to supplement grazing cattle is often dependent upon price and availability of supplement, forage quality, desired target weight of the calves, and length of ownership. Winter supplementation of calves is usually necessary for adequate growth when the base forage is low quality such as dormant native range or cornstalk residue. Many producers will supplement to target a low rate of gain (≤ 1.0 lb/d) during the winter planning to take advantage of compensatory gain on growing summer grass. However, depending on the severity and length of restriction, calves may not fully compensate. Calves supplemented at a higher winter backgrounding rate have been shown to be heavier at the end of summer grazing, requiring fewer days on feed in the feedlot, or resulting in more carcass weight to sell at slaughter (Drouillard et al., 1991; Jordan et al., 2000; Jenkins et al. 2009; Gillespie-Lewis et al., 2015).

Jenkins et al. (2009) supplemented dried distillers grains (DDGS) at 0%, 0.25%, 0.50%, or 0.75% BW to calves (450 lb) grazing dormant winter range for 56 days. Calves then grazed wheat pasture without supplementation for 76 days. The calves exhibited a linear response ($P < 0.001$) to increasing level of supplementation on native range (Table 1). Calves not supplemented on range exhibited compensatory gain once on wheat pasture, resulting in the same body weight as the calves supplemented DDGS at 0.25% BW, negating any benefit to supplementing that low level. Final body weight after wheat pasture grazing was greatest for the calves supplemented 0.50% and 0.75% BW (Table 2). Economic analyses of the supplementation strategies at various prices of DDGS and value of added gain suggested that producers selling calves after grazing dormant range made the most money by supplementing at 0.75% BW. Those selling after wheat pasture grazing were more likely to profit from feeding at 0.50% BW on native range. These data suggest supplementing DDGS at 0.25% BW on winter range and selling calves after grazing range, was not the most profitable strategy even when DDGS was high and the value of gain was low. For producers selling after grazing wheat pasture, the 0.25% BW supplementation level resulted in a loss because of compensatory gain.

Table 1. Initial BW, amount of supplement, ADG, and total BW gain of steers grazing dormant range supplemented with dried distillers grains (Jenkins et al., 2009).

	Treatment, % BW DDGS				
	0.00	0.25	0.50	0.75	SE
Initial BW, lb	449	451	451	451	2.2
Supplement, lb/d	0	1.12	2.25	3.4	
Daily gain[ab], lb/d	0.59	1.06	1.41	1.72	0.08
Total BW gain[ab], lb	32.8	59.6	79.2	96.6	4.6
Final BW[ac], lb	482	510	530	548	4.4

[a]Linear Contrast (*P* < 0.001)
[b,c]Linear Contrast (*P* = 0.16, 06, respectively)

Table 2. Wheat pasture performance of growing steers previously supplemented with dried distillers grains (DDGS) while grazing native range (Jenkins et al., 2009)

	Treatment, % BW DDGS				
	0.00	0.25	0.50	0.75	SE
Initial BW[a], lb	475	502	521	532	11
Daily gain[b], lb/d	1.98	1.60	1.74	1.62	0.18
Total BW gain[b], lb	151	122	132	123	13.6
Final BW[c], lb	625	625	653	656	17.6
Compensation of nonsupplemented control, %	---	100	38	46	---

[a]Linear Contrast (*P* < 0.001)
[b,c]Linear Contrast (*P* = 0.13, 08, respectively)

In a meta-analysis of 6 studies, Gillespie-Lewis et al. (2015) evaluated past research wintering cattle targeted to gain approximately 0.5 lb/d on the low gain treatments and 1.5 lb/d on the high gain treatments. In all 6 studies, cattle were in a three phase system where they were wintered on poor quality forage with supplementation, then grazed summer grass with no supplementation followed by a finishing phase. Profitability was evaluated using high and low prices for distillers grains. Cattle supplemented for low gain in the winter only compensated 37% during the summer (Table 3). Those authors reported that while the cattle supplemented for low gain in the winter compensated with a higher average daily gain than the cattle supplemented for high gain, they did not weigh more at the end of the summer. The cattle supplemented for high gain in the winter then tended (*P* < 0.06) to have greater finishing gain and did have a greater final body weight (*P* < 0.01). This improved performance resulted in overall profitability being greater for the cattle supplemented for high winter gain than those supplemented for low winter gain regardless of distillers price being high (110% of corn priced at $7.00/bu or relatively low (80% of corn priced at $3.00/bu). These data suggest that while compensatory summer gain does exist, the advantage of the winter weight gain from the higher level of supplementation is likely going to be maintained through the summer and subsequent finishing period.

Table 3. Backgrounding and finishing average performance across six systems studies comparing winter supplementation level (Gillespie-Lewis et al., 2015)

	Low[1]	High[2]	SEM	*P*-value
Winter backgrounding phase				
Initial BW, lb	499	497	11.3	0.28
Average Daily Gain, lb/d	0.61	1.39	0.09	< 0.01
Days on Feed, winter grazing	144	144		
Ending BW, lb	585	695	20.7	<0.01
Summer grazing phase				
Average Daily Gain, lb/d	1.34	1.06	0.09	0.01
Days on Feed, summer grazing	138	138		
Ending BW, lb	768	840	16.8	0.02
Compensation, %	37			
Finishing phase				
Average Daily Gain, lb/d	3.98	4.15	0.24	0.06
Days on Feed	116	113	5.36	0.53
Total Dry matter intake	3252	3201	114.8	0.71
Feed:gain or efficiency	7.04	6.83	--	0.19
Final BW, lb	1230	1307	21.8	< 0.01

[1,] cattle supplemented for low (0.5 lb/d) or high (1.5 lb/d) rate of gain during the winter

Summer supplementation for developing feeder calves. Supplementing cattle grazing summer grass is not a popular practice among stocker operations. There may be several reasons for this including labor, logistics, and commodity availability. However, some producers may not supplement on summer grass because they assume the cattle will not consume the supplement or the supplement would not result in additional gain. Extensive research has shown cattle will consume supplement on high quality pasture and that it does result in increased gain. Martinez-Perez et al. (2013) fed increasing levels of DDGS on native summer range in New Mexico effectively increasing body weight gain and replacing some forage intake. Buttrey et al. (2012) supplemented growing steers on wheat pasture (23.7% crude protein; 19.3% acid detergent fiber) and found that not only was daily gain increased due to supplementation, but that stocking rate could be increased by 10-12.5% due to forage replacement. However, when the steers were subsequently retained through the finishing phase, the pasture supplementation advantage was not maintained. Griffin et al. (2012) supplemented steers grazing cool season meadow grasses through the summer and also observed a positive gain response to supplementation. That study reported that in one experiment the weight gain was maintained through the finishing period and in the other experiment it was not. Watson et al. (2015) reported increased gain and ending body weight for steers supplemented DDGS while grazing smooth bromegrass, but inconsistent results on whether the cattle maintained that advantage through the finishing period. Greenwell et al. (2018) reported an increase in gain for growing calves supplemented a blend of dry rolled corn, solubles and urea or field peas over the gain of calves not supplemented while grazing crested wheatgrass in the summer. In that study, pasture gain was greatest for the corn blend, intermediate for the field peas, and least for the non-supplemented calves. Net profit for the grazing period was greatest for the corn blend. Supplementing with field peas was the most expensive because a human consumption market value was assessed on the field peas. In that study, the control cattle exhibited compensatory gain during the finishing phase and subsequently there was no performance difference due to grazing treatments after finishing, making the net profit greatest for the non-supplemented cattle. Troyer et al. (2020) compared supplementing DDGS to field peas to determine a salvage value for the field peas and determined that field peas, when considering relative performance and transportation costs, should be discounted about 10% the cost of delivered DDGS when used for cattle feed as opposed to human consumption. These studies suggest summer supplementation is most likely to be profitable if calves are sold prior to feedlot entry, and if supplement cost is minimized.

One way to save money on supplement is to reduce waste. Musgrave et al. (2012) compared feeding loose DDGS on the ground or in a bunk and found a significant average daily gain advantage to feeding in a bunk (1.19 vs 0.92 lb/d; $P < 0.001$). Pesta et al. (2012) compared feeding loose DDGS on the ground, DDGS made into a cube with field peas as a binder and fed on the ground, or loose DDGS in a bunk. They reported average daily gain of 1.34, 1.56, and 1.54 lb/d gain respectively. The gain for the bunk and cube were not different but were greater than the loose DDGS fed on the ground. These two studies estimated the loss of supplement fed on the ground to be 38.5% and 25.6%, respectively. When supplement cost is high, waste is a significant expense.

Recent research has indicated another way to reduce supplement cost is to only feed supplement the last half of the grazing season. In a study reported by Watson et al. (2015) steers grazing smooth bromegrass were fed DDGS at 0.5% BW either throughout the grazing season or the last half and compared to a non-supplemented control. In that study, the supplemented steers outweighed the non-supplemented controls. Interestingly, there was no statistical difference between the daily gain and ending body weight of the two supplemented groups and the cattle in the deferred supplementation group consumed 20% less supplement (Table 4). This weight gain advantage was maintained through the finishing phase. An unpublished study conducted at the High Plains Ag Lab near Sidney, NE was recently completed. This study used steers (750 lb) in year 1, heifers (579 lb) in year 2, and steers (766 lb) in year 3 to compare feeding supplement the entire grazing season (110 days) or only the last half to a non-supplemented control. Cattle were supplemented 3 lb/hd/d on a dry matter basis regardless of body weight. Supplemented calves gained more than non-supplemented calves, but the two supplemented groups were not statistically different (Table 5). The group supplemented the last half of the grazing season consumed 50% less supplement but had similar ending body weight. These cattle were sold prior to the finishing phase.

Table 4. Growing and finishing performance of steers grazing smooth bromegrass and supplemented with dried distillers grains plus solubles (Watson et al., 2015)

	Treatment[1]				
	NOS	SP	DSP	SEM	*P*-value
Initial BW, lb	464	464	464	8.4	0.99
Ending BW, lb	748[b]	847[a]	847[a]	28.2	< 0.01
ADG, lb	1.41[b]	1.94[a]	2.00[a]	0.07	< 0.01
Feedlot final BW, lb	1254	1320	1331	16.7	< 0.01
HCW, lb	741	790	794	10.3	< 0.01
Marbling score[2]	611	614	622	14.6	0.76
LM area in.^{2}	11.25	11.81	11.97	0.17	< 0.01
12th –rib fat, in.	0.38	0.39	0.41	0.02	0.33

[ab]Means within a row with unlike superscripts differ ($P < 0.05$)

[1]NOS = no supplement, SP = supplement daily, DSP= deferred supplement until after 56 days grazing, DDGS, supplement fed at 0.5% BW

[2]400=slight^0, 450=slight^{50}, 500 = small^0

Table 5. Performance of growing calves grazing crested wheatgrass and supplemented with dried distillers gains (Wilke et al., unpublished data)

	Treatment[1]				
	CON	FULL	HALF	SE	*P*-value
Initial BW, lb	701	696	699	19.2	0.98
Interim BW, lb	829	855	849	16.3	0.51
Ending BW, lb	871[a]	924[b]	916[b]	16.0	0.05
Overall ADG	1.52[a]	2.05[b]	1.95[b]	0.07	< 0.001
Last half ADG	0.83[a]	1.39[b]	1.36[b]	0.12	<0.001

[1]CON=control (no supplement), FULL = 3lb DDGS (DM basis) May to September, HALF = 3 lb DDGS (DM basis) last hay of grazing season (July to September)

Summary

Maintaining yearling cattle in addition to the cow-calf herd can provide producers with some income diversification as well as a drought mitigation tool. Winter supplementation for a target of at least 1.0 lb/d gain has been shown to be maintained through the finishing period. When supplementing for a target gain of less than 1.0 lb/d, compensatory gain on summer grass will result in a negative net return from the supplementation input. Supplementing on summer pasture when logistically feasible, can result in a positive net return when cattle are sold prior to finishing in most cases. Research suggests that supplementing the last half of the summer can result in the same gain as supplementing all summer with less input costs.

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Use of GPS technology to better understand livestock behavior

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History of Livestock Tracking

Quantifying and understanding grazing livestock behavior and resource selection on extensive rangelands has been an important question for researchers and grazing practitioners for decades. A Nebraska study conducted in the early 1940s evaluated livestock grazing behavior over several days during the summer grazing period (Brinegar and Keim 1942). Researchers followed cattle over a 24 hr period and recorded cattle location and behavior (resting, grazing, etc) every 30 minutes. Nighttime was a noted challenge, with researchers indicating that full moon nights were best for recording observations because it limited the need for car headlights. Though challenging to conduct, this study provided some of the first insights into the amount of time cattle spent grazing (11 to 12 hours per day) as well as grazing selection on different landscapes in the central Great Plains. Other studies have used visual observations to evaluate differences in individual animal habitat use on the landscape, predict spatial patterns of livestock behavior within pastures, and quantify the effects of distance to water and pasture size on cattle activity and forage utilization (Senft et al. 1983; Hart et al. 1993; Howery et al. 1996). These early studies were pivotal in understanding the influence water and landscape features on livestock behavior and pasture utilization, and helped shape management recommendations for livestock producers.

In the late 1990s, the use of visual observations for studying cattle behavior was replaced by GPS tracking systems. The development of GPS technology allowed researchers to continuously monitor livestock locations over longer time frames and greater frequencies across a range of environments. A Web of Science search with the key words “GPS”, “Collars”, and “Cattle” shows that studies using GPS-tracking capabilities on cattle has increased steadily from 1 or 2 articles per year in the early 2000’s to more than 15 articles per year in the last few years (Fig. 1). Though this search includes studies not specific to range beef cattle, it highlights the utility of GPS technology for collecting and studying cattle behavior.

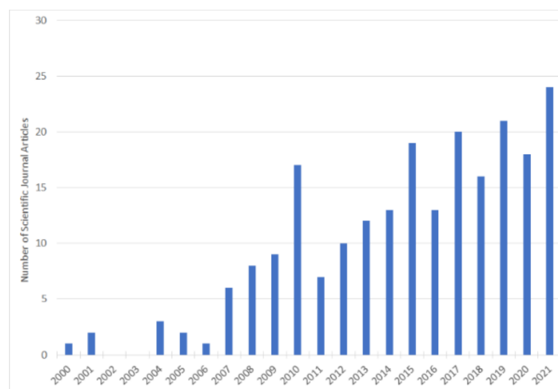

Figure 1. Web of Science search results of research articles using the terms “GPS”, “collars”, and “cattle” as search criteria (www.webofscience.com, accessed October 6, 2021).

GPS-tracking technologies provide increased opportunities for researchers to ask novel questions to better understand grazing behavior under diverse management scenarios (Fig.2). These devices store animal location (latitude/longitude) at defined intervals (e.g. 10 minutes) that are accessed and analyzed following deployment (Swain et al. 2011; Bailey et al. 2018). One of the main benefits to using GPS data is the ability to continuously monitor cattle locations and pair these locations with landscape features mapped using computer software (Putfarken et al. 2008). For example, GPS technology has been used to study livestock grazing patterns within patch burned pastures (Augustine and Derner, 2014); influence of landscape topography on grazing patterns (Raynor et al. 2021); strategies to improve livestock distribution through placement of low moisture blocks and low-stress herding (Bailey et al., 2008; Stephenson et al. 2017); and the relation of forage quality to livestock distribution (Zengeya et al. 2013). Other studies have utilized GPS tracking to better understand the relationship between individual cows within a herd (Stephenson et al. 2017a) and the influence of livestock genetics on grazing distribution relative to the distance cattle travel from water and average elevation climb (Bailey et al. 2015). Though much knowledge has been gained through the use of GPS technology to study factors that drive livestock distribution on the landscape, adoption of these technologies has been limited primarily to researchers within university and government organizations. This is in large part due to the previously high cost (~$1,500) of commercially available livestock tracking devices which are often cost prohibitive for both researchers and producers alike. Recent adoption of off the shelf GPS tracking devices has effectively been used to track range beef cattle at a substantially reduced costs, potentially increasing accessibility of this technology to livestock producers.

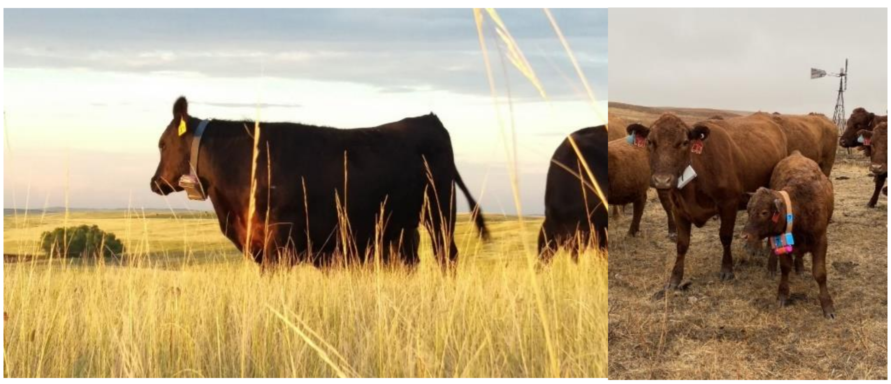

Figure 2: A yearling steer wearing a GPS collar at the SDSU Cottonwood Field Station. A cow and calf wearing GPS collars at the UNL Gudmundsen Sandhills Laboratory near Whitman, Nebraska (Picture by Selby Boerman).

Lab/Homemade GPS devices

Relatively inexpensive, readily available GPS components can be purchased and retrofitted with larger batteries and homemade collars (Knight et al. 2018, Brennan et al. 2021; Sprinkle et al. 2021). For example, Knight et al. (2018) used a commercially available, all-in-one GPS receiver and data logger common for vehicle fleet tracking and retroactively fitted a larger battery to extend the life for GPS collection. Total cost for the final GPS collar (including collar strap, housing for GPS unit and battery, etc) was approximately $200. Karl and Sprinkle (2019) developed GPS-collars using open source GPS, data logging, and battery components with a total cost of only $54.78. However, the authors indicated three limitations to their collar design were reliability of their design construction, poor battery life, and more GPS fix misses than the GPS receivers used by Knight et al. (2018). McGranahan et al. (2018) developed a similar low-cost GPS unit with open hardware components for approximately $125. These lab made devices can also include motion sensing technology such as 3-axis accelerometers that can help identify GPS locations associated with animal behaviors such as grazing, resting, and walking to better understand livestock selection on the landscape (Augustine and Derner 2013; Brennan et al. 2021, Sprinkle et al. 2021). The referenced articles above have detailed lists of components and costs to develop low-cost GPS-units; however, skills required to build these devices can vary from soldering on larger battery packs on electrical boards, to altering and uploading computer code to microprocessors. In addition, deploying GPS collars on free ranging livestock also poses practical challenges including the ruggedness of the collars, battery life, and accuracy of the GPS receiver. Researchers and producers utilizing GPS collars, can expect a proportion (5% to 15%) of those collars to 1) run out of battery sooner than expected, 2) break or fall off cattle, or 3) stop working because of exposure to elements. This failure of the technology has been observed in both commercially built and home-made options for GPS tracking and should be considered in determining the number of animals to collar with GPS units.

Applications of GPS technology for producers

Livestock grazing distribution, stocking rate, class of livestock, and timing of grazing, are some of the primary grazing management variables that can be directly influenced by a livestock producer (Valentine 2001). Livestock grazing distribution refers to the uniform dispersion of grazing across a given landscape or management unit. Poor livestock grazing distribution can cause rangeland degradation in specific areas, even if stocking rates are appropriately set for the pasture (Bailey 2005). As a result, grazing distribution is one of biggest challenges on rangelands, with many livestock producers having areas of their pastures that are either under- or over- utilized.

Livestock grazing distribution is influenced by a number of abiotic and biotic factors on rangelands. Abiotic variables in the pasture include horizontal and vertical distance cattle need to travel from water, topography, slope position, and elevation rise. Biotic variables include the quantity, quality, type, and distribution of vegetation available for forage within the pasture. GPS-tracking of livestock has been used to evaluate how these variables that influence grazing intensities across a landscape. Raynor et al. (2021) utilized data from GPS-tracked cattle at 7 research stations across the United States to evaluate the effect of topography on grazing use. These researchers found that topography alone could be used to predict grazing locations and that GPS-tracked cattle utilized lowlands 120% more intensively than associated uplands. Rugged topography, large distances to water, and low stock densities contributed to poor grazing distribution in the study, whereas small, well-watered pastures grazed at higher stock densities exhibited more uniform grazing across a landscape. In addition, breed of cattle and genetic traits can also influence grazing distribution on the landscape (Bailey et al. 2015), and livestock producers may consider utilizing heritage livestock breeds that best match their climate and rangeland (Allred et al. 2013; Nyamuryekung'e et al. 2020).

While livestock grazing distribution challenges are not new, GPS tracking of cattle grazing may become an important tool for monitoring grazing use across the landscape at production scales. Modeling livestock grazing patterns can help researchers and grazing practitioners better understand how differences in management strategies influence rangeland health, wildlife habitat, or livestock production objectives. These data could be used to assist in developing grazing strategies or guiding grazing decisions. For example, visualization of cattle grazing intensity based on time spent grazing in specific areas of a pasture provides clear opportunities to improve pasture management by strategic placement of water and fence (either temporary or permanent) in areas that would improve grazing distribution (Fig. 3). More uniform utilization across a landscape reduces overgrazing at preferred areas and increases grazing use at locations that are only lightly grazed, thereby increasing harvest efficiency. The information received from GPS tracking could also inform conservation management decisions such as identifying livestock use within environmentally sensitive areas, and give producers insight into differences in vegetation structure and composition to tailor grazing rotations based on production and conservation goals.

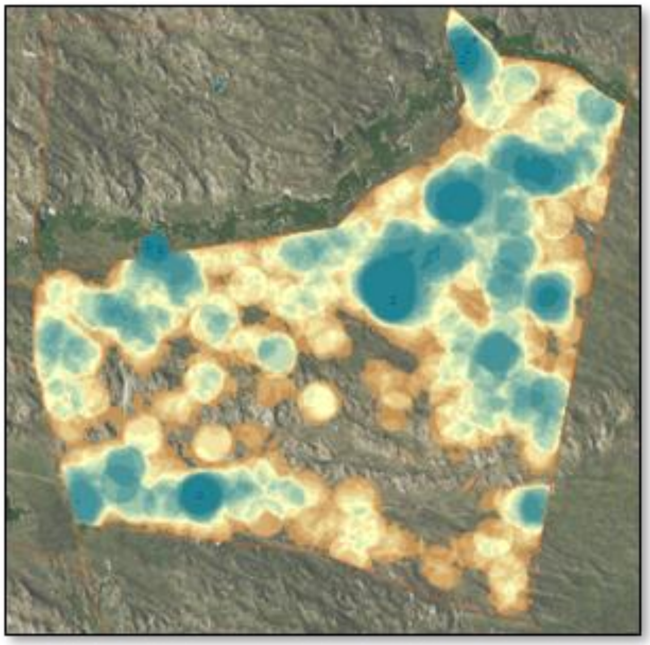

Figure 3. A point density map for a 1,500 acre pasture highlighting point densities of 10 GPS-track cows. BLUE represents areas of the pastures with high point densities, or areas with higher grazing intensity. BROWN and NO-COLOR represents areas with low point densities, or areas with minimal grazing intensity.

Water and fencing locations are one of the most effective tools for manipulating grazing distribution on the landscape. However, water and fence development are expensive and may not always increase output and therefore economic return on the investment (Dyer et al. 2021). As highlighted above, GPS technology can help identify over- or under- utilized areas of pasture to inform decisions on cross-fencing or water development to 1) separate preferred and avoided locations, 2) decrease distance cattle need to travel to grazing sites, and 3) increase stocking density. The use of high-tinsel electric fence has allowed for more opportunities to divide pastures into smaller paddocks at a more reasonable cost; however, some areas are too remote, rough, or lack adequate water to use these tools effectively.

Other techniques to improve livestock grazing distribution include strategic supplementation placement to attract cattle to underutilized areas. In a Montana study, cattle were attracted to upland areas away from water with the use of low-moisture block protein supplement (Bailey et al. 2001). In this study, grazing uniformity of upland areas was increased within 600 m of low-moisture block protein placements. A combination of low-moisture block and low-stress herding effectively increased grazing use at strategic locations away from water that typically received low grazing pressure during winter in the southwest USA (Stephenson et al. 2017). This research indicated that as time spent near supplement locations increased, grazing utilization within surrounding areas also increased. If cattle did not consume supplement because of supplement unpalatability, novel supplements, or adequate nutrition in available growing forage during the spring, then supplements did not provide any added benefit to attracting cattle to lightly grazed areas in the pastures. These studies highlight the applicability of using GPS technology to study supplementation and herding strategies on livestock distribution. One benefit of GPS-technology research is to better understand management strategies that can be implemented by producers without the need for tracking their own animals within a herd. This can be beneficial as the learning curve for processing and analyzing large geospatial datasets in meaningful ways can be steep and often requires specialized skills.

Advances in GPS data processing tools have been created to make data analysis more accessible to producers and researcher interested in collecting their own GPS data (Fig. 4) (Champion and Sukianto, 2020). In addition, as technological costs have come down for GPS tracking technology, many commercially available options are available for producers interested in tracking livestock. Often times these commercially available options provide data analysis platforms, mapping software, and built in analytics to help users gain insights from their data on animal health, efficiency metrics, and landscape use. Exploring the benefits of commercially available products may be more applicable to livestock producers that want a more user friendly off the shelf option. In addition, by incorporating radio or satellite communication technology into GPS collars or ear tags, a greater number of commercial options offer the ability to monitor livestock locations in near-real time, greatly adding to the utility of GPS technology for making timely livestock management decisions.

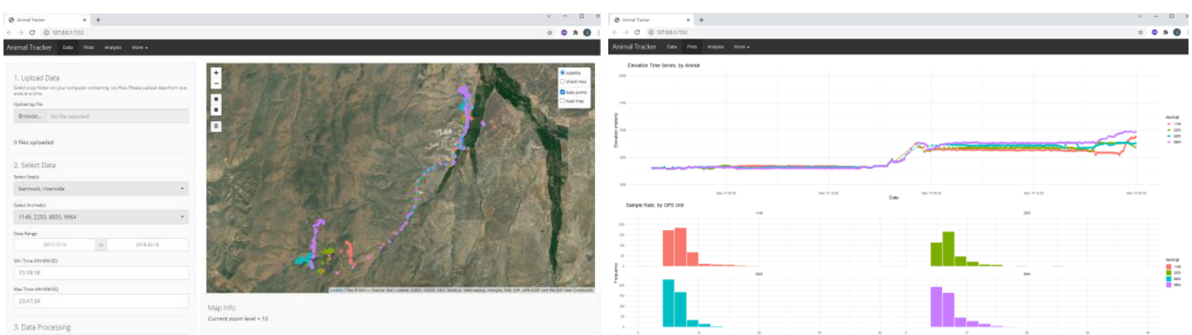

Figure 4. Screen shot of Animal Tracker web application developed by Oregon State University. The web application allows researchers and producers to upload, display, and create analyses of GPS data.

Real – time GPS data

Numerous studies have demonstrated the utility of tracking livestock with GPS technology, but limited research exists using real time data capture on extensive rangelands. The possibility of having real-time GPS tracking opens up multiple options for application to livestock producers including immediate alerts for when animals are outside of pasture boundaries, or help locating animals in large pastures (Fig. 5). This may be especially valuable in remote locations where rough terrain or travel distance limits frequent opportunities for livestock managers to visually observe cattle welfare. Knowing when cattle escape or are not within defined areas would also provide reassurance to managers that cattle are where they are supposed to be at any given time with alerts to phones or emails if cattle escape a pasture.

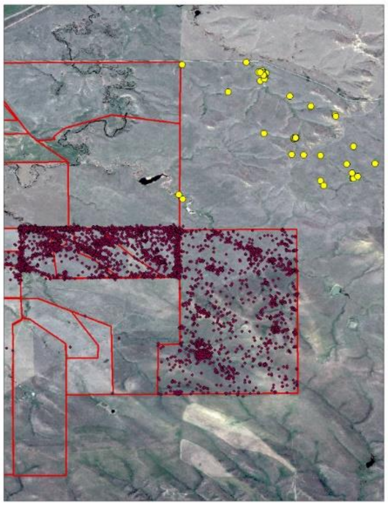

Figure 5. Real-time GPS tracking data for a yearling steer at the SDSU Cottonwood Research Station. Large yellow points in the upper right corner are locations where the steer escaped the property perimeter fence into the neighbors pasture. The animal was quickly located and returned to the property upon escape.

In addition, real-time tracking of animals may help identify sick individuals within a pasture or other issues of concern. For instance, tracking variability in movements associated with GPS-tracked cattle is an effective way to monitor livestock welfare such as water failure (Tobin et al. 2021) or disease detection with the added use of motion sensors (Tobin et al. 2020). Identifying when lambing is occurring in sheep also shows promise with GPS systems based on algorithms linked to changes in ewe behavior at the time of lambing (Fogarty et al. 2021). Algorithms that can alert producers to changes in behavior associated with distress, sickness, or parturition may provide time-saving opportunities for producers to address these challenges.

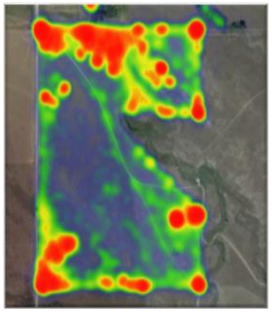

Figure 6. Real-time heat map of livestock use within a pasture. Red indicates areas of heavy use by the herd

Having real time information on grazing behaviors could also assist livestock producers with decisions on when to move cattle to a new pasture. For example, real time heat maps of grazing locations within a pasture can be used to identify areas that are being overgrazed and may need to be fenced out using temporary fences (Fig. 6). Additionally, the amount of time spent within riparian zones could be a metric for when cattle need to be moved or other management employed to reduce overgrazing on these sensitive rangeland areas. Social association patterns, herd spread, and distance traveled among cattle could also be used as metrics in determining when cattle are searching for more palatable forage as utilization increases at preferred locations (Tobin et al. 2021a). In the future, this technology may provide options to grazing managers to monitor locations of the entire herd, track changes in individual or herd behavior, and identify key metrics to monitor health, welfare, or grazing management remotely and with little added input.

Producer input

According to the USDA National Agricultural Statistical Service (NASS), the number of farmworkers declined from 9.93 million in 1950 to 3.19 million in 2000, a 68% reduction (ERS, 2021, www.ers.usda.gov/topics/farm-economy/farm-labor, Accessed 10/10/2021). In addition, an estimated 82% of U.S. farm income comes from off-farm work (Bunge and Newman, 2018). This shift in the work force will continue to require creative solutions to accomplish agriculture objectives. The advancement of technology may provide opportunities to efficiently improve range beef cow management while simultaneously reducing labor costs for the producer. This technological transformation has become commonplace in row cropping systems where the use of drones, precision seeders, yield monitors, and targeted applications have helped maximize yields and reduce inputs.

Consider the advancement of grazing management tools for many ranches in the Great Plains. The history of manipulating where cattle graze on a landscape has evolved from herding cattle to new grazing locations in expansive and open rangeland systems, to barbed-wire fence providing constraints on where cattle graze, to the less expensive electric fence that has changed our ability to employ more intensively managed grazing for specific animal and rangeland objectives. In the future virtual fence technologies with GPS-tracking abilities may provide economically viable options to further limit cost and labor associated with managing cattle grazing dispersion (Anderson et al. 2014). The use of GPS-tracking to better understand and facilitate management is currently a real possibility. Utilizing data derived from GPS-tracked cattle provides a resource that can assist with grazing management decisions, but these tools are best used with a thorough understanding of the rangeland and forage resources, livestock behavior, and other husbandry practices. Though technology offers many opportunities to increase farm efficiency, it will not be able to replace producer experiential knowledge of their operation and herd. Many skills such as visual observations of rangeland utilization, health and body conditioning, and livestock handling will continue to require active management by trained practitioners. Key to the success and adoption of these technologies for range beef cattle production is input and insight from livestock producers.

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A SYSTEMS APPROACH TO RANCHING: FEEDING COWS DURING FEED SHORTAGES

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INTRODUCTION

Increasing volatility in commodity and cattle markets and extreme variance in climatic conditions has become the new normal. Recently, drought in many parts of the high plains has left beef producers exposed to a great deal of production and financial risk. Drought conditions during most of 2021 have now prompted feed shortages. Couple this with significantly higher crop prices and now many producers face making decisions that could influence long-term production and profitability. Drought strategies usually involve some combination of supplemental feeding and culling. However, unintended, or invisible costs should be analyzed. Great management requires the ability to navigate through the current situation while keeping an eye on the future.

In most grazing operations, supplementation is necessary to meet production goals (i.e., biological, and economic). Current forage conditions will likely require feeding to maintain cattle inventories. Feeding cows is expensive (largest expense for most cow-calf operations) and has a major impact on profitability. In the high plains, winter feed costs can account for 60-80 percent of this expense. Efficient use of forage resources and reducing supplemental feed cost is key to becoming a lower-cost producer. Hay is particularly expensive which may force many to seek a lower cost alternative. In drought regions of the high plains, hay prices are 60-70% higher than last year. With hay in short supply and more expensive, concern for cost effectively acquiring fall/winter feed supplies has intensified. It is typically not cost effective to feed out of a drought situation (depends on feed costs, current and expected market prices, and duration of drought) but rebuilding the cow herd is also costly. Reducing feed costs requires enhanced management. To begin, a comparison of different management approaches through systems analysis can be an effective tool to evaluate risk and options, as well as foster an atmosphere of strategic long-term planning. If maintaining the herd is a goal, producers should consider multiple strategies including 1) developing a strategic supplementation program; 2) analyzing the destocking strategy; and 3) managing the cowherd differently.

A SYSTEMS APPROACH

Ranching is becoming more complex than ever. In recent years, persistent drought has plagued producers making it difficult to remain solvent. Drought has greatly decreased forage availability, often leaving producers with two basic options: purchase hay at inflated prices or downsize the cowherd. In ranching, systems' thinking provides us with a framework to generate effective management alternatives for complex decision making. A systems map was created by developing mental models and assessing the interconnection of ranch components and decision-making processes. This framework also allowed us to identify management alternatives that might reduce the impact of the unintended consequences associated with the current situation. External forces, such as drought and high feed prices, tend to drive a systems behavior. The response is seldom simple, and impact can vary depending on the ranch system in place.

Feed shortages also make it more difficult to control costs. Higher input costs (i.e., labor, supplemental feed, and depreciation), has caused some producers to continue to struggle with maintaining cow numbers. With that in mind, we used a systems thinking approach to address the challenge: "Why is it so difficult to cost-effectively maintain a cowherd during drought?" The task was to describe the problem and identify a few high leverage management alternatives that would better enable ranch managers to cost-effectively navigate the challenges feed shortages create for long term ranch sustainability.

A systems map is a useful tool to better understand a problem and identify leverage within a complex system. Figure 1 illustrates a systems map of the feed shortage dilemma. When a system faces an external pressure, the corrective action works to reduce that pressure in the form of a balancing loop. A balancing loop is a goal seeking structure that minimizes the difference between the actual and desired state of a current metric (e.g., available feed). For example, if a ranch produces 500 pounds of hay per acre but requires 1,500 pounds to satisfy the number of Animal Unit Months (AUMs) then a deficit of 1,000 pounds exists (e.g., 500 – 1,500 = -1,000 lb.). To balance or close this 1,000-pound deficit the ranch will need to implement management strategies. In our diagram, there is a current "*pressure to acquire feed*" and "pressure to reduce herd size", while the subsequent "*purchasing feed*" and "*selling cows*" keeps this portion of the system in balance (Figure 1: B1-2). The third distinct balancing loop suggests there is a "*feed shortage*" while "*identifying alternative grazing practices*" and it's subsequent "*implementation of alternative practices*" would keep this portion of the system in balance (Figure 1: B3). Together the balancing loops create a classic systems structure known as shifting the burden, where the two upper balancing loops represent short-term fixes that balance while the lower balancing loop is associated with a long-term fix that will create balance given the opportunity. When management faces a problem or pressure (i.e., feed shortage) the natural reaction is to respond quickly to reduce the short-term pressure. However, longer-term solutions are often more difficult and take more time to implement. It is not that managers are unaware of the value of longer-term solutions; rather they become dependent upon a quick fix. These quick fixes can generate unintended consequences (i.e., inflated cowherd breakeven costs) that are not always visible prior to decision making. The consequences can make it virtually impossible to engage in the long-term solution.

These unintended consequences form reinforcing (R) loops within the system. Building upon the previous example, the "*purchasing of feed*" would cause "*higher feed costs*" and "*selling cows*" would cause "cowherd breakeven costs" to increase leading to a decline in the ability to "*cost effectively maintain the cowherd*", and ultimately reducing the ability of the ranch to "*implement alternative practices*" to address long-term feed shortages. Additionally, on the top side of the diagram, if "*feed shortage*" is not addressed through one of the previously discussed balancing loops, then a "*pressure to overgraze*" leads to "*overgrazing*" and a decline in "*rangeland condition*", then after some delay resulting in greater "*feed shortage*" longer-term. The "*purchasing feed*" and "*selling cows*" reduces grazing pressure and stocking rate to minimize "overgrazing" and reduce the effect of the "overgrazing" reinforcing loop. These are examples of what seems to be a logical or rational short-term decision (i.e., purchasing feed and selling cows) that can lead to unintended consequences which make it difficult to meet ranch goals (cost effectively maintain cowherd) and implement long-term solutions (alternative grazing practices).

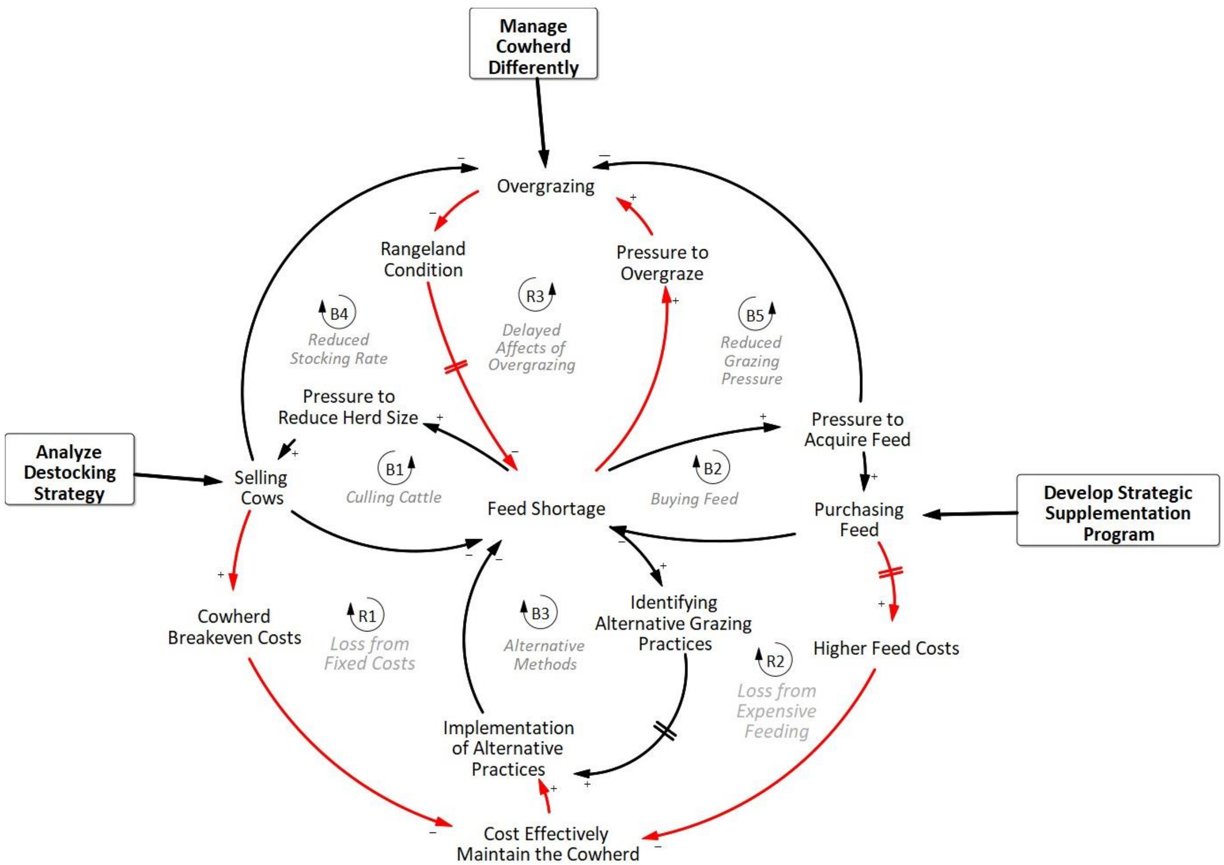

Figure 1. Causal Loop Diagram of cattle herd feed shortage dynamics during drought. Where, solid black boxes represent intervention strategies, black lines represent balancing loops (B), red lines represent reinforcing loops (R), "+" represents same direction, "-" represents opposite direction, and grey-italicized names represent each loop name.

MANAGEMENT STRATEGIES

How will your operation be successful given this complex dynamic? The entire system obviously hinges on the impact precipitation has on availability and price of feed resources. However, since precipitation or commodity specific feed prices cannot be controlled, three high leverage management alternatives were identified: 1) develop a strategic supplementation program; 2) analyze the destocking strategy; and 3) manage the cowherd differently. It is important to evaluate your own ranching system to identify the appropriate practices, there is no best solution.

1. **Develop A Strategic Supplementation Program:** This assumes that range grazing is an option (i.e., enough forage availability) and destocking or an appropriate stocking rate has already been applied. This management alternative allows for the reduction of "*high feed costs*" which increases the ranches ability to "*cost effectively maintain cowherd*" and reduces the impact of the reinforcing loop.

   Determining forage quantity and quality is the first step in designing an economical supplementation program. If continued grazing is still in play and stretching the existing forage base is the objective, then identifying a cost-effective supplement is required. Consider regularly analyzing all available forage sources (i.e., range and harvested). Start by testing forage sources for protein and energy content to determine if additional supplementation is needed. This allows you to match forage resources to cow requirements and avoid nutrition gaps or wasting costly nutrients. Determining if forage is providing adequate nutrition to meet the cow's nutrient requirements is the first step. Many factors can influence this dynamic (i.e., season, stage of production, intake etc.). Even if forage supply is adequate, protein or energy may be limited. Start by estimating forage quality (i.e., records, observation, or sample analysis) to determine the amount of nutrients cows will obtain. Once forage analysis has been collected and cow nutrient requirements have been established, simply compare to determine if a deficiency exists. Supplements come in many forms. Make a list of options that fit the system (i.e., availability, storage, equipment required, etc.). Additionally, above average mature cowherd body condition may allow for some small differences to exist between meeting exact supplemental needs. Meaning, cows in excellent condition might be able to lose some condition without hurting overall cow longevity and performance, including calving percentage and calf weaning weight.

   Selecting the right method and frequency of supplementation delivery is vital to employing the most cost-effective program. Hand feeding provides a tool for gathering cows and decreases intake variability but will likely increase labor cost associated with delivery. Interval feeding can reduce fuel expense and labor. A 30 percent or greater CP supplement can be fed as few as 1 to 2 times per week and a 20 percent or less CP supplement should be fed at least every other day.

   An effective program will factor in the cost of available supplements. Hand fed supplements (i.e., cubes or cake) allow more flexibility for least cost formulation. Consider evaluating available supplements on a cost per unit of nutrient provided. An example cost calculation: 30 percent CP supplement at $250 per ton = (2000 pounds X 30 percent CP = 600 pounds CP) (600 pounds CP / $250 per ton) = $0.42 per pound CP. Cost per pound of nutrient simplifies choosing the most economical supplement. The goal of minimizing purchased feed cost is the common link among each consideration. It is often a challenge to decide which supplementation system best fits your operation. There are a range of solutions, pick the system that provides the targeted amount of nutrients and minimizes costs.

2. **Analyze The Destocking Strategy**: This is a high leverage point directly impacting the "*cowherd breakeven costs*" of the ranch during feed shortage. It also assumes that range grazing is still an option. This analysis should provide insights into the most economical destocking strategy to employ by limiting the inherent increase in "cowherd breakeven costs" that typically follows a destocking event. This would also increase the ranches' ability to "*cost effectively maintain cowherd*" by reducing the impact of the reinforcing loop.

   It is important to consider all production stages (calves, replacements, and cows). Heifer calves represent genetic progress and require less feed than a cow. An early pregnancy check should have been conducted which allows for quick culling of late-bred heifers or cows and shortens the next breeding season. All open cows should be culled. After that, be careful before depopulating the "factory" to deep. Fewer mature cows will lead to fewer calves to sell in subsequent years.

   Margins are tightening and the ability to cash flow until feed becomes more plentiful is critical. Analysis of production costs utilizing accurate production and financial records offers important benchmark data for decision-making. Annual cow costs are ranging from $950-1050 per cow on average. Cow-calf businesses are asset based, meaning fixed costs can account for greater than 60% of this total cow cost annually. Fixed costs structure on a ranch is difficult to change once assets (equipment, labor, and cows) have been acquired. The most effective way to lower fixed costs is to spread it out over more units or increase cow numbers. Maintaining or even increasing stocking rate relative to fixed cost is an important concept to remain efficient and profitable. Culling too many cows must be looked at cautiously to avoid unintended consequences.

   Accurate financial records are key to making management decisions easier. Determine if it is economical to provide supplemental feed. If destocking is still the best option, sell cattle (weaned calves, inferior cows, etc.) before excessive weight is lost and market prices decline. There is a cost (e.g., time) associated with evaluating the numbers. However, time spent evaluating data makes decision making more quantitative (i.e., objective) reducing guess work and costly errors. The saying is true, "it is difficult to manage what isn't measured". Few ranchers enjoy recordkeeping, but good records support sound management in the face of rising costs, weather uncertainty and volatile markets. There are numerous tools, calculators, and ranch planning resources that can assist with making these calculations. Advanced planning to avoid a bigger crisis is the common link among each consideration.

3. **Manage The Cowherd Differently:** This was also determined to be a potentially feasible long-term management alternative. However, it assumes that range grazing is not an option due to severely limited forage conditions. In turn, this alternative allows the ranch to reduce or eliminate the potential for "*overgrazing*" and avoid the reinforcing loop beginning with "*pressure to overgraze*" during a feed shortage.

   Excessive grazing (> 60 percent of current year's growth) decreases some plants ability to recover. Overgrazing reduces long-term carrying capacity and ranch profitability (up to 50% reduction in Net Income over a 10-year period). Destocking should help to avoid excessive feed costs and protect the resource base. However, if pastures are extremely poor and continued grazing is not an option, then consider limit feeding in a sacrificed pasture or drylot. Drylot feeding requires intensive management (e.g., feed storage, mixing equipment, feed space and bunks) but can be more cost effective than supplementation or destocking since small amounts of roughage are fed and the cowherd can be maintained. It also allows pastures to rest and recover from drought. When hay prices are high, grain is usually cheaper per unit of nutrient. Transition cows to high concentrate diets gradually and ensure adequate bunk space.

If forage for grazing is severely limited and drylot feeding is not feasible, then consider utilizing crop residues (corn stalks, wheat straw, sorghum-sudan). Quality of residue starts high but declines over time. Grazing right after harvest guarantees the highest quality residue. Initial quality is related to amount of grain, husk, and leaf. Rate of forage quality decline depends on stocking rate and weather. Protein supplementation might not be needed, depending on amount of residual grain and class of cattle grazing. By-products (distillers' grains, corn gluten, etc.), high in protein and energy are good supplemental feeds, if priced right. Dry, pregnant, mature cows are ideal due to lower nutrient requirements. Conduct a nutritional analysis and test for nitrates. Nutrient content of crop residues is generally like low-quality forage (3-5 percent CP). Exploring alternative feeding programs is the common link among each consideration.

Successful management alternatives will provide flexibility to protect the core business (i.e., cowherd). The above-mentioned strategies are not necessarily applicable to all ranching operations, but they represent potential leverage points capable of helping to avoid the long-term consequences associated with quick decisions during difficult times. Developing a strategic supplementation program on the operation can significantly reduce feed cost without much investment. Analyzing the destocking strategy varies from ranch to ranch, so there is no one solution for all. Managing the cowherd differently by changing the feeding system could provide increased flexibility even when feed shortage is not a concern. Seeing the entire structure of why it so difficult to cost effectively maintain the cowherd allows managers to find long-term solutions for their own operation.

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RANGELAND SOIL HEALTH: INTERACTIONS WITH VEGETATIVE RECOVERY

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INTRODUCTION

Recent research indicates that grazing lands and croplands have lost about 128 billion tons of carbon (C) from the soil during the 12,000 years since agriculture started (Sanderman et al., 2017). That's over a quarter of the C that human activities have added to the atmosphere since the start of the industrial revolution. This represents massive land degradation and loss of productivity. The authors estimate that about half the lost soil C is from grazing lands and about half from croplands; however, grazing lands cover about twice the area as crop lands. The silver lining may be that soil C loss underlies opportunities to improve soil health and productivity by managing land to remove C from the atmosphere and store it in the soil.

Carbon makes up about 50 to 60% of soil organic matter (SOM), which is the primary component of healthy soils. Although SOM makes up only about 1 to 3% of the dry mass of rangeland soils, it supports nutrient cycling, water infiltration and storage, resistance to erosion, breakdown of toxins, and many other functions that we associate with healthy soil. SOM is made up of plant and animal residues in all stages of decomposition. It both supports and is created by diverse microbial populations that drive decomposition and nutrient cycling. About half the SOM in undisturbed soil is in stable organo-mineral complexes (Figure 1). Much of the other half is made up of simple sugars, amino acids, and metabolic plant tissues that are easily decomposed to provide nutrients for plants and microbes, but about half of that active portion is locked inside stable soil aggregates and is protected from microbial break down. Stable soil aggregates are created when organic compounds bridge sand, silt, and clay particles together to form soil structure with stable macropores and micropores. Plant residues, actively decomposing compounds, and materials protected inside aggregates represent most of the SOM lost from soil disturbed by agriculture and other activities, as well as the portion that can be recovered with improved management.

Although soil animals and microbes are key players in changing and stabilizing SOM, healthy vegetation and healthy soil are inextricably linked, because the ultimate source of SOM is photosynthesis. Plants absorb carbon dioxide (CO_2) from the air and create a broad spectrum of C-based compounds, from easily decomposed metabolic tissues to resistant, structural substances like lignan. Living plants deposit about 11% of the C they take in from the air into the soil in a large number of different substances, creating an enriched near-root environment – or rhizosphere – that supports microbial activity, speeds up nutrient cycling, and enhances uptake (Jones et al., 2009; Khatoon et al., 2020). Residues of dead plant tissues, whether seasonal deposits from perennials or whole annual plants, are rapidly decomposed and partitioned into stable, aggregate-protected, and active SOM components.

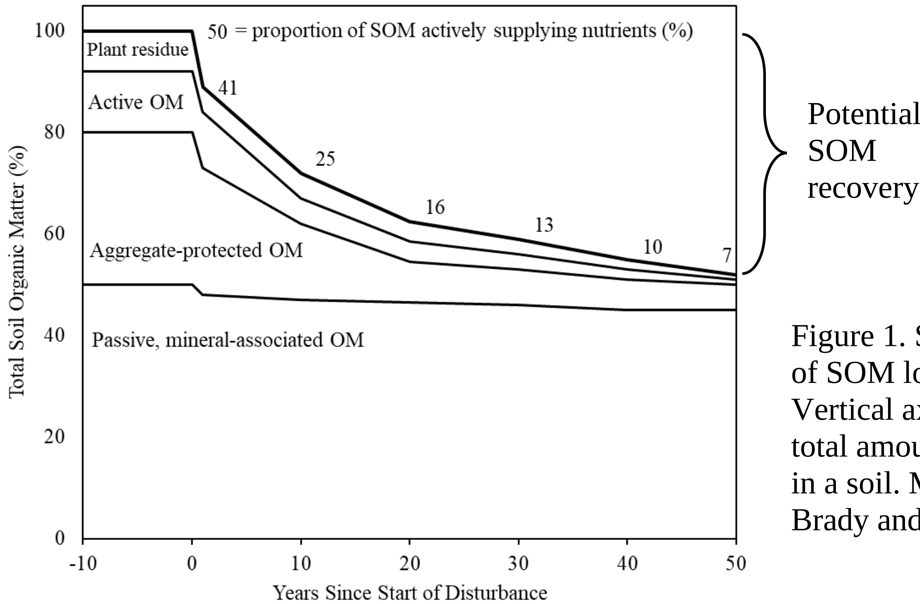


Figure 1. Schematic diagram of SOM loss with disturbance. Vertical axis represents the total amount of organic matter in a soil. Modified from Brady and Weil (1999).

In their global study, Sanderman et al. (2017) noted that soil C loss was not evenly distributed but concentrated in hotspots associated with major cropping regions and degraded grazing lands. They suggest that these regions could be targets for SOM restoration. The same could be true on the scale of a farm or ranch. Most of the area may be in good condition with healthy soil and thriving vegetation, but there may be hotspots of degradation related to concentrated livestock grazing or trailing, vehicle traffic, past cultivation or mismanagement, more fragile soils, or a combination of factors. These could be focus areas for restoring soil health and vegetative productivity. The key is to identify those areas and diagnose soil health issues that constrain soil functions, then adopt management practices that support recovery.

ASSESSING RANGELAND SOIL HEALTH

Soil health is defined as the capacity of a soil to be used productively without adversely affecting its future productivity, the ecosystem or the environment (USDA-NRCS, 2021). More succinctly, it is the capacity of the soil to function. The ways that we expect soil to function depend on broad management objectives, or ecosystem services. In rangelands, if the main objective is forage production, the soil needs to provide nutrients, water, and physical stability for vegetation as well as performing these functions under stress. The soil should be resistant to change and resilient to unusual events, like drought or intense rainfall (Andrews et al., 2004). Other rangeland objectives supported by overlapping soil functions include environmental protection and waste cycling, supported by the functions listed in Table 1. In soil health assessment, the soil's capacity to perform these functions is measured with specific soil tests, or soil health indicators.

Table 1. Soil functions and examples of soil health indicators.

Soil Functions	**Description**	**Example Indicators Provided by Laboratories**
Nutrient Cycling	High potential to hold and release optimal amounts of essential plant nutrients.	Microbial biomass, mineralizable nitrogen, pH, SOM or OC
Water properties	Water movement and storage potential for plant growth, deep percolation, resistance to erosion.	Water-holding capacity, bulk density, salinity, sodicity, pH
Physical stability	Soil structure that provides porosity and resistance to erosion.	Aggregate stability, bulk density, pH
Filtering/buffering	Absorbing and degrading toxins or pH changes.	SOM or OC, bulk density
Resistance/ resilience	The stability of other functions. Resistance = maintain function; Resilience = continue to function.	Soil depth, SOM or OC
Biodiversity/ habitat	Supports variety of plants and animals. Supports other functions.	Soil microbial functional diversity, respiration

Diagnosing degraded soil health in croplands might require laboratory tests because fertilizers, pesticides, and other modern farming tools support high yields, even when other soil ecosystem services, such as environmental protection and waste cycling, cease.

In rangelands, lower than expected productivity and species shifts toward opportunistic vegetation – both native plants and weeds – are often the first clues that soil functions might not be supporting management objectives. Diagnosing rangeland soil problems might start with some simple observations to compare areas of concern with areas thought to be functioning well. Table 2 summarizes a three-tiered approach to rangeland soil health assessment, including simple visual observations, simple field tests, and laboratory tests.

Table 2. Stepwise levels of soil health indicators. For additional information see the Rangeland Soil Health link at https://soilmanagement.wordpress.com/.

Level:	1 Observations	2 Field tests	3 Lab tests
Leave the field with:	Information	Information	Soil samples
Tools:	Shovel, knife, notebook, GPS	Level 1 plus some simple tools and instruments	Level 1 plus sampling bags and a cooler with ice
Indicators:	Amount of bare soil Surface horizon depth Signs of erosion Structure/aggregation Soil texture Penetration resistance Salt accumulation Moisture content	Soil bulk density Ponded infiltration Aggregate stability Soil pH Soil EC Lime content Plant available N and P	Soil organic matter or Soil organic carbon Plant available nutrients Active carbon Biologically available N Salinity/sodicity

When compared with a reference area (an area thought to be functioning at or near its potential), Level 1 observations provide information about erosion of the surface horizon, compaction, and the strength of the soil structure. These simple observations might be enough to support changes grazing pressure, trailing routes, or livestock concentrations.

If Level 1 doesn't provide convincing evidence to explain loss of productivity, then Level 2, along with an investment in tools like a pH/EC meter, an aggregate stability kit, and some simple nitrate and phosphate tests, might achieve that. Elevated electrical conductivity (EC, indicating salt content) can indicate either loss of surface soils or changes in hydrology that causes salts to accumulate at the surface. Changes in hydrology could be seasonally raising the water table or causing deposition of salt-rich sediments. Increases in pH mean increased alkalinity, which limits plant nutrient uptake and can indicate increased sodium or loss of surface horizons (Norton, 2020). Decreased stable aggregate content can follow changes in EC and pH or can be caused by direct disturbances from hoof action and compaction. Levels of plant available N and P can be tricky to interpret because they are often in low supply where healthy rangeland plants take them up as fast as they become available. Typically, they should be present, but not at high levels, which suggest disrupted nutrient cycling that leads to weed invasion and indicates SOM loss.

Level 3 tests are done by soil laboratories to look at active SOM loss or recovery (see Figure 1) compared with a good reference area. These measurements should accompany observations of compaction, bare soil, and signs of erosion because alone they can also be tricky to interpret in rangelands. For an extreme example, manure and waste hay has high levels of active SOM and nutrients, so the tests could suggest that a feeding area or corral has good soil health even if there is no forage production and the soil is compacted or eroded.

Overall, soil health and vegetation health form two sides of a crucial feedback relationship where loss of plant cover leads to loss of soil structure, compaction, and erosion, ultimately reducing SOM content and making restoration more and more difficult. Conversely, successful restoration of desirable plant cover often requires restoration of soil function, especially conditions for seed germination and establishment at the soil surface. Once that is accomplished vegetative recovery and soil health recovery support each other.

SOIL AND VEGETATION RECOVERY: DRASTICALLY DISTURBED RANGELANDS

Soils disturbed by mining and drilling activities are completely stripped off and replaced when the site is reclaimed. Reclamation procedures include salvaging topsoil to 6-inch depth and subsoil to varying depth, stockpiling the soil during mining or drilling, then respreading, tilling, and seeding when mining or drilling is complete. Such drastic disturbances allow us to track redevelopment of soil functions and vegetation recovery. We monitored topsoil SOM changes at three well pads in Wyoming big sagebrush-steppe grasslands at the Jonah Natural Gas Well Field in Sublette County, Wyoming. We sampled the soil predisturbance, in the stockpile, right after reclamation, one year after reclamation, and then returned seven years later. Surface horizons typically lose about half their total SOM from a combination of disturbance effects that accelerate microbial decomposition and mixing of very shallow A horizons with upper subsoils within the 6-inch salvage depth (Figure 2).

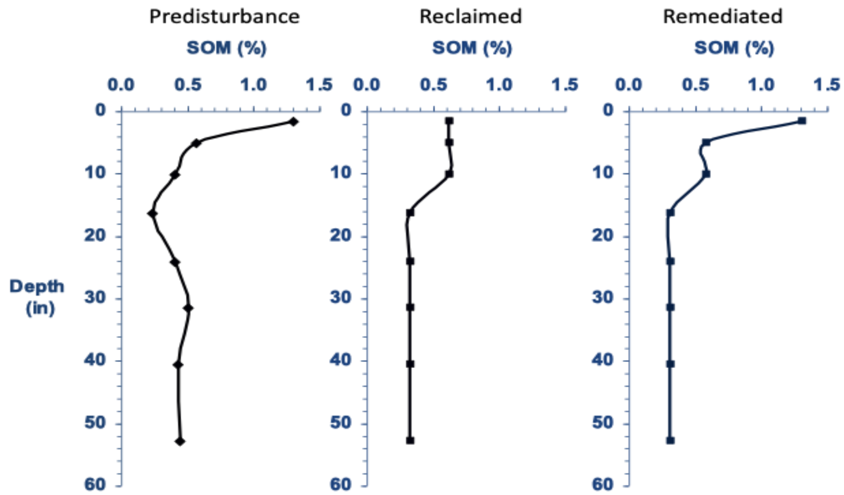


Figure 2. Changes in total SOM content after soil removal and replacement in representative soil profiles sampled during natural gas well development and reclamation.

Seven years after reclamation, thin A horizons had begun to develop and plant cover had shifted from exotic annual weeds, especially Russian thistle, to a rich mix of planted grasses forbs and sagebrush (Figure 3).

Figure 3. Vegetation recovery on a Jonah Field gas well pad from one year after reclamation (2011), dominated by Russian thistle and other weeds, to seven years after reclamation (2017), dominated by planted native grasses, forbs, and shrubs.

Active SOM responded dynamically to salvage and reclamation activities (Figure 4). Predisturbance soils had very low levels of mineral (plant-available) N and a higher active C:N ratio of about 14 (PMC:PMN), both of which we expect in an intact rangeland soil where N is limiting and strongly competed for among plants and microbes. Scraping and stockpiling caused a pulse of decomposition, increasing plant available N and active C and N, after soil aggregates were pulverized and crushed vegetation was mixed with the soil.

Respreading the stockpiled topsoil caused a large pulse of decomposition, loss of much of the active C and N, and increases in plant-available N concentrations that amounted to about 50 pounds of N per acre, much of which was gone one year later. We think this disturbance-effect N release explains the proliferation of annual weeds following reclamation. While not desirable vegetation, the weeds acted as a cover crop, adding SOM to the soil, providing soil cover, and protecting native seedlings during favorable weather conditions in the following years. Synergistic plant-soil processes improved soil conditions and facilitated establishment of the planted native grasses, forbs, and shrubs. Seven years after reclamation, total SOM had returned to predisturbance levels in the surface soil. But active C and N (PMC and PMN) are recovering more slowly, possibly due to continued accelerated decomposition and slowly recovering soil aggregates that protect active C and N.

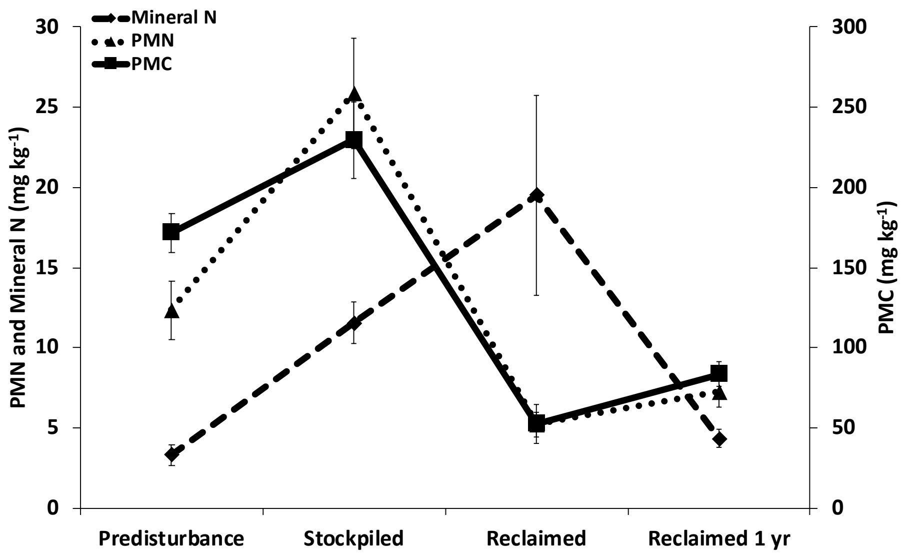


Figure 4. Average concentrations active SOM components (6-inch depth) across three natural gas well pads and four sampling times at the Jonah Field in Wyoming (Mason et al., 2011).

SOIL AND VEGETATIVE RECOVERY: CHRONICALLY DISTURBED RANGELANDS

Chronic disturbance in the form of heavy long-term, season-long grazing, long-term weed infestation, or changes in drainage and hydrology degrade soils in a plant-soil feedback that reduces resilience. Weaker vegetation adds less and less SOM, inputs of manure or rapidly cycling weedy residues prime accelerated microbial decomposition, and more rapid drying both accelerates decomposition and limits plant growth. In this section I review two studies in sagebrush-steppe rangelands, one of long-term cheatgrass infestation in the Great Basin of Utah (Norton et al., 2004), and one of long-term, season-long grazing on herbaceous riparian areas in central Wyoming (Booth et al., 2021).

Cheatgrass is an invasive annual grass that has invaded large areas of shrub-steppe ecosystems in the Western United States and is now dominant across much of the Great Basin, Snake River Plain, and Columbia Plain. The area covered and ecological degradation rivals impacts of conversion from perennial grasslands to annual crops that took place in the Midwest and Great Plains regions. Conversion of native shrub-steppe to cheatgrass affects SOM in ways that result in similar impacts to those of conversion to annual crops: 1) frequent fires volatize plant materials and reduce inputs to SOM; 2) lower root:shoot ratios compared with native grasses and shrubs; 3) higher litter decomposition rates; 4) soil structure degradation because of lower rhizosphere deposition from short-lived roots; and 5) altered soil microbial communities. In a study of seven paired native and long-term cheatgrass-dominated sites in Utah and southern Idaho we sought to quantify long-term effects of altered processes on SOM storage and flow and other soil properties.

The density of roots in near surface soil was one of the most striking visual differences between shrub-steppe vegetation, which had a rich mixture of coarse to very fine roots, and cheatgrass, which had only a very high density of very fine roots. Cheatgrass plants die by early summer, leaving a low-density, highly porous surface horizon with aeration effects akin to cultivation. A horizons were also much thinner under cheatgrass than under native vegetation. Death of all the plant biomass in early summer causes microbial decomposition and release of plant-available N that is out of sync with plant uptake, creating a leaky SOM system where N is no longer a limiting nutrient. We measured higher plant-available N levels under cheatgrass, especially in upper subsurface horizons, than under shrub-steppe vegetation, which characteristically have very tight N cycling with little accumulation of plant-available N. Total SOM and organic C levels were often the same or higher under cheatgrass than native vegetation at the surface, but dropped to near zero within 30-cm depth (12 inches) under cheatgrass, reflecting the very shallow root system (Figure 5a).

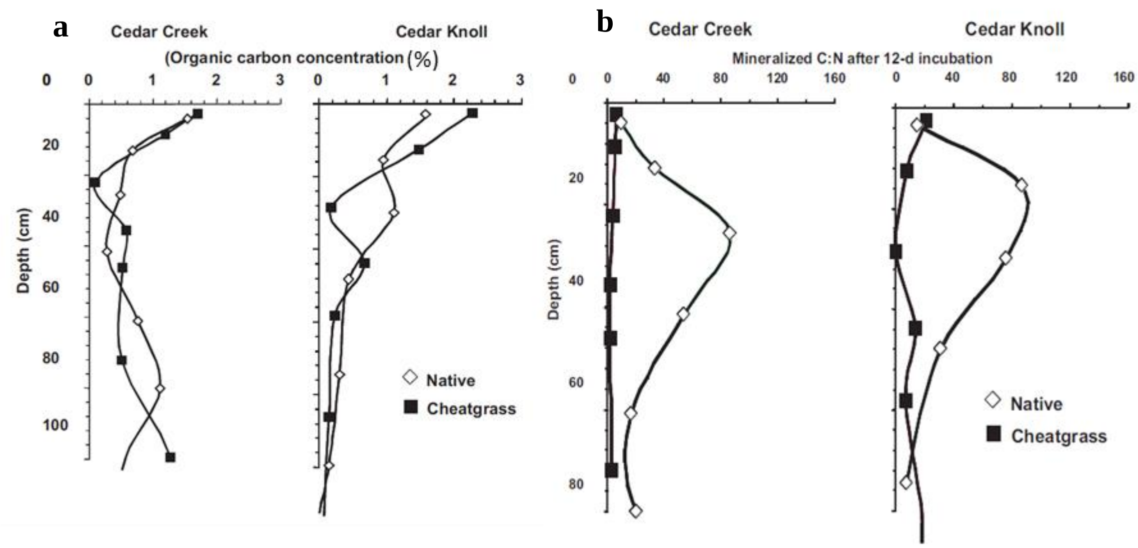


Figure 5. Soil organic C concentration (a) and active-pool C:N (b) in paired soil profiles under cheatgrass-dominated and Wyoming big sagebrush-steppe vegetation.

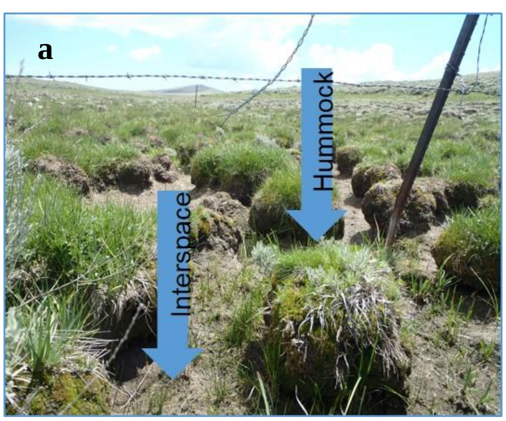
Carbon:N ratios generally narrowed in surface horizons, reflecting loss of C to the atmosphere and retention of N in lower C:N weedy plant tissues. Active C:N ratios narrowed markedly in upper subsurface horizons (Figure 5b), reflecting equivalent amounts of active C but an influx of active N under cheatgrass. We think that this is because the shift away from perennial vegetation and complete loss of woody plants caused more rapid SOM cycling with increased microbial respiration that causes loss of C as CO_2.

In climates with appreciable summer precipitation, cheatgrass and other weedy annual plant species rapidly colonize disturbed areas and then start to redevelop the functions of the A horizon. This sets the stage for reestablishment of native perennial vegetation, behaving much as the weedy plants on drastically disturbed sites described above. But in strongly Mediterranean climates, with moist winters and very dry summers, cheatgrass persists, increasing fire frequency and eventually dominating the plant community. As climate change strains the resiliency of native vegetation to more frequent shocks in the form of drought, intense rain, wildfires, and storms, cheatgrass may become more persistent in areas like the northern Great Plains.

Restoration of native plant communities in long-term cheatgrass-dominated rangelands requires first preventing fire with targeted grazing (Diamond et al., 2009) or greenstrips to create fuel breaks (Porensky et al., 2018). Even as a minor component of a plant community, cheatgrass can create continuous fine fuels in otherwise patchy plant communities. This results in much larger, overlapping fires with frequency that limits vegetation recovery. Once protected from fires, remnant native vegetation starts to recover or seed mixes that include hardy, competitive, and quick-establishing natives begin to "re-perennialize" the soil, reestablishing functions that support recovery of diverse perennial vegetation.

High elevation Wyoming big sagebrush grasslands of central Wyoming are dissected by stringer meadows with year-round water and much higher vegetation production than surrounding uplands. This is one reason that thousands of pioneers, with millions of livestock, crossed the basin on the way to South Pass and the west side of the continental divide, following the Mormon Pioneer, Oregon, California, and Pony Express trails. That migration marks the start of over 150 years of continuous, season-long grazing. Starting in the 1980s, the Bureau of Land Management (BLM) built exclosures in some of the degraded riparian areas to monitor effects of little or no grazing.

Many of the riparian wetlands originally had organic soil surface horizons that formed a thatch mat almost floating on the saturated soil underneath. Pioneers reported finding ice beneath the organic horizons well into the summer. Cattle hooves punched through the organic soil, eventually forming pedestals 12 to 18 inches tall, many still capped by remnant organic horizons. The deep interspaces form cattle trails and channels that accelerate drainage and lower the water table in the riparian meadows (Figure 6a). The increased surface area in the pedestalled area, along with little plant residue accumulation, significantly increases soil temperatures compared with soil inside grazing exclosures (Booth et al., 2021).



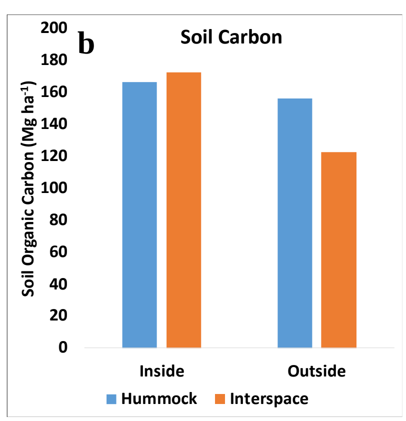


Figure 6. Degraded riparian meadow with hummocked remnant surfaces and compacted interspaces (a) and increases in soil organic C in interspaces inside long-term exclosures

(b) (one Mg ha^{-1} = about ½ ton $acre^{-1}$).

Our examination of the exclosures, many of which retain lighter, seasonal grazing indicate that these functions begin to recover within 8 to 30 years of changing to managed grazing systems. Soil temperatures are much lower where plant residues are retained for fall and winter cover. Hummocks are still present, but interspaces have largely filled in with sediment and organic material that retains water for prolonged stream flow (Figure 6b). In 2011 the BLM began managing grazing to retain cover on the riparian meadows. These resilient systems are beginning to recover to provide more forage, biodiversity, and water.

SUMMARY AND CONCLUSIONS

Soil health and vigorous, diverse, nutritious vegetation are tightly linked because SOM, which is key to almost all the functions of healthy soils, is made of decomposed plant residues. Healthy soils provide water, nutrients, and stability that allow plants to fix more CO_2 from the atmosphere, ultimately increasing SOM and soil health. Assessing rangeland soil health starts with visual observations of lower-than-expected plant productivity or shifts toward weedy vegetation that indicate one or more soil functions is compromised. Simple observations of soil surface conditions, like signs of erosion, crusting, ease of penetration with a knife, and the thickness of the A horizon compared with nearby properly functioning areas might provide enough evidence for management changes, or they might warrant additional field and laboratory tests to diagnose soil health problems.

It follows that soil degradation and loss of forage production go together, as do their recovery. Studies of drastic and chronic disturbance emphasize the resilience of rangeland soils and plant communities. When drivers of degradation are removed, plants begin to deposit residues above and below ground and soil functions recover, setting the stage for recovery of diverse, productive vegetation and the ecosystem services it provides.

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Cattle and beef market outlook

Patrick Linnell - Analyst
CattleFax

NOTES

State ballot initiatives - panel

Senator Gary Cammack – South Dakota
Senator Ogden Driskill – Wyoming
Terry Fankhouser – Colorado Cattlemen's Association Executive Vice President
Ashley Kohls - Nebraska Vice President of Government Affairs

NOTES

Proceedings, The Range Beef Cow Symposium XXVII
November 16 & 17, 2021, Rapid City, South Dakota

DEVELOPING REPLACEMENT HEIFERS: CAN WE PROGRAM FERTILITY?

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Introduction

Development of replacement heifers is a major economic investment, with costs associated with managing heifers prior to weaning their first calf recovered through subsequent calf crops. In beef cow-calf operations, profitability can be directly tied to the productive lifespan of cows within the herd. Management decisions made over the first year of life can influence heifer performance and reproduction, as well as play a key role in establishing heifer fertility and longevity. Therefore, it is critical to understand not only how management practices affect reproductive performance and lifetime productivity, but evaluate if fertility can be enhanced based on the development strategies utilized. The association among nutritional management, puberty attainment, and pregnancy rates in heifers is well established (reviewed in Patterson et al., 1992, Funston et al., 2012). Traditionally, development of replacement heifers has considered puberty attainment as the foremost factor (Patterson et al., 1992). Nutritional management and growth rate during the post-weaning development period have been determined to be important factors influencing age at puberty and reproductive performance in beef heifers (Joubert, 1954; Short and Bellows, 1971; Wiltbank et al., 1985; Patterson et al., 1992). Therefore, the focus of heifer development research has been on the impact of management strategies on reproductive performance, with a major focus of past and current research on nutritional management.

While management strategies have changed over time due to shifts in cattle genetics, selection, and management, successful development strategies must be put in place that allow heifers to reach their reproductive potential. Reproductive traits have a four times greater impact on profitability than other production and consumption traits (Melton, 1995). Due to the significant impact of reproduction and longevity on overall profitability of cow–calf operations, it is critical to identify management strategies that can potentially improve lifetime productivity. Nutritional management represents a crucial aspect of cow-calf operations where management practices and decisions can have a significant influence on reproductive performance. Recent studies investigating nutritional management and programming during the peripubertal developmental period have reported that developing heifers on a stair-step nutritional regime increased the size of the ovarian reserve (Freetly et al., 2014; Amundson et al., 2015; Rosasco et al., 2020) potentially increasing reproductive longevity in beef cows (Freetly et al., 2021). These results further demonstrate the interaction between nutrition and reproduction, as well as suggest that specific nutritional management systems may improve herd fertility and longevity.

Heifer Development Systems

The primary goal of development of replacement heifers is to optimize reproductive performance, economic efficiency, and lifetime productivity of heifers. Heifers are expected to grow to 65-75% of mature size, attain puberty, and produce their first calf within the first 2 years of life (Summers et al., 2019). Considerable research contributed to the guideline that heifers should be developed to 60 to 65% of mature body weight at the start of the breeding season (reviewed in Patterson et al., 1992; Funston et al., 2012). This research demonstrated that limiting post-weaning growth negatively impacted age at puberty attainment and pregnancy rates (Joubert, 1954; Short and Bellows, 1971; Wiltbank et al., 1985). Studies evaluating different target body weights and post-weaning rates of gains have explored countless nutritional strategies and feeds to evaluate the relationship among reproduction and nutrition. The target body weight approach, specifically the recommendation that heifers be developed on a higher rate of gain to at least 60 to 65% mature body weight by the start of the breeding season, became the industry standard. During the time when this research was conducted (1960-1980's) there was a readily available supply of inexpensive feed sources, allowing for increased use of cereal grains and harvested forages within heifer development systems making it more affordable to raise heifers to 60 to 65% mature body weight.

Research over the last several decades has demonstrated that there has been a shift in the association among heifer body weight, puberty, and pregnancy rates (reviewed in Funston et al., 2012; Endecott et al., 2013). The shift in the relationship among puberty attainment, fertility, and body weight is likely a result of increased selection pressure for age at puberty and fertility, as well as changes in genetics over time. Several management factors contributing to this have been suggested, including the change in the industry standard of calving heifers at 3 years of age to calving heifers at 2 years of age, the association between bull scrotal circumference and daughter age at puberty, and potential changes in the relationship between the timing of puberty attainment prior to the breeding season and subsequent pregnancy rates (Funston et al., 2012; Endecott et al., 2013). Together these factors suggest an overall increase in selection pressure for age at puberty and fertility in general has occurred within the industry. Recent heifer development research has emphasized comparing traditional, more intensive systems to low-input extensive development systems. Increased development costs, driven by increased feed costs has been a significant driver behind investigation of more extensive heifer development systems. Low-input heifer development systems have typically relied on grazing heifers on dormant forages or native range, developing heifers to a lighter percent mature body weight, and(or) rely on periods of compensatory gain. The objective of more extensive low-input systems has been to develop management strategies that are more economically efficient for producers while maintaining reproductive performance in heifers (Lynch et al., 1997; Freetly et al., 2001; Mulliniks et al., 2013; Summers et al., 2014). Traditional target body weight development research suggested that heifers below the 60 to 65% mature body weight threshold at the start of the breeding season would have reduced reproductive performance because of an increased percentage of non-cycling heifers. Protocols that develop heifers to a lighter target body weight at breeding (50 to 57% of mature body weight) have reduced development costs while not impairing reproductive performance. Martin et al. (2008) reported that heifers can be developed to as low as 50% of mature body weight and maintain similar pregnancy rates as heifers developed to 57% mature body weight over a 60-day breeding season. Funston and Deutscher (2004) reported heifers developed to 53% mature body weight prior to the breeding season had reduced body weight and percentage of heifers cycling prior to the breeding season compared to cohorts at 58% mature body weight. Pregnancy rates, however, were similar among heifers developed to 53 or 58% mature body weight.

Studies comparing post-weaning nutritional management of heifers are inconsistent regarding the impacts of extensive development systems on age at puberty or the percentage of heifers cycling at the start of the breeding season (reviewed in Summers et al., 2019). Overall heifer pregnancy rates, however, have been demonstrated to be similar regardless of if heifers were managed in extensive, low-input heifer development system or in traditional heifer development systems (Lynch et al., 1997; Freetly et al., 2001; Funston and Deutscher, 2004; Mulliniks et al., 2013; Summers et al., 2014). Heifers may, therefore, be developed to lighter than traditional target body weights or managed in lower input development systems without detrimental effects on reproductive performance. Management of heifers to maximize economic efficiency and ensure development costs can be recuperated in a timely manner is an important consideration when making decisions regarding how to develop and manage replacement heifers. Furthermore, available resources vary among operations, therefore, development systems are unique to each operation. Effective utilization of resources that allows for optimal reproductive performance of heifers not only in their first breeding season but over their lifetime is an essential component of heifer development systems. Research has established that heifers that calve in the first 21 days of their first calving season have increased longevity in the herd and wean more pounds of calf over their lifetime compared with heifers calving in the second or third 21-day calving period (Cushman et al., 2013). Therefore, development of management strategies that focus on heifers conceiving early in their first breeding season can help increase survivability and lifetime productivity of heifers.

Nutritional Programming of Fertility in Heifers

Developmental or nutritional programming is often synonymous with fetal programming; however, nutritional programming has also been shown to be effective during the first year of life in heifers. Nutritional programming during postnatal development of heifers has been shown to influence puberty attainment as well as the size of the ovarian reserve (Cushman and Perry, 2019). As indicated previously, there is substantial research demonstrating that age at puberty is directly influenced by nutritional management. Heifers developed on extremely low planes of nutrition can experience delayed puberty (Gonzalez-Padilla et al., 1975). The frequency of precocious puberty in beef heifers can be increased when heifers are weaned early and managed on a high concentrate diet (Gasser et a., 2006). While limited, previous research has suggested pre-weaning body weight gain influences age at puberty more than post-weaning growth (Cardoso et al., 2014; Roberts et al., 2017). Recent research has evaluated programming the onset of puberty through use of stair-step type diets where nutrition is increased and decreased during different developmental windows. The onset of puberty occurred at a younger age in heifers fed to target a high rate of gain between 4 and 6 months of age compared to heifers fed to attain a low rate of gain during the same developmental window (Cardoso et al., 2014). In the same study, heifers fed to attain a low rate of gain between 4 and 6 months of age, who were then stepped up to target a high rate of gain from 6 to 9 months of age, had the majority of heifers attain puberty between 11 and 14 months of age

(Cardoso et al., 2014). These results would suggest that the timing of puberty can be programmed to occur before the start of the breeding season, while limiting the incidence of precocious puberty associated with high rates of gain during the juvenile period.

Nutritional programming during the peripubertal development period has also been reported to influence the size of the ovarian reserve in beef heifers. Primordial follicles formed during gestation represent the ovarian reserve and the growing pool of follicles the animal will utilize over her reproductive lifespan. Previous research has suggested the size of the ovarian reserve corresponds with fertility in cattle (Cushman et al., 2009; Mossa et al., 2012). Previously, it was believed heifers are born with a finite number of follicles within their ovaries, the ovarian reserve, and depletion of the ovarian reserve occurred at a constant rate that cannot be altered (Rajakoski, 1960; Erickson, 1966; Scaramuzzi et al., 2011). Research evaluating the influence of nutrient intake on the ovarian reserve, however, has demonstrated that nutrition can influence primordial follicle numbers in the ovary of both rodents and cattle. Recent research in cattle has evaluated the impact of altering growth patterns through nutritional management on the ovarian reserve. Freetly et al. (2014) reported heifers on a stair-step nutritional scheme, where caloric intake was reduced between 8 and 11 months of age and then increased between 11 and 14 months of age, had an increased number of primordial follicles at 14 months of age compared to control heifers developed on a constant rate of caloric intake from 8 to 14 months of age (Freetly et al., 2014). Amundson et al. (2015) developed heifers in a drylot utilizing the same single-phase stair-step development system and ovariectomized heifers at 3 different time points to determine when differences in the ovarian reserve occurred. Primordial follicle numbers were similar among treatments at 8 and 11 months of age, however, stair-step heifers had an increased number of primordial follicles at 13 months of age compared to control heifers (Amundson et al., 2015). Mechanisms controlling the number of primordial follicles, however, are poorly understood. Slowing depletion of the primordial follicle pool through either slowing the rate of activation of primordial follicles or stimulating formation of new primordial follicles could increase the size of the ovarian reserve at the start of the breeding season and potentially allow for an increase in the reproductive lifespan of cows. It is important to note, once primordial follicles are activated and transition into the growing pool of follicles the process cannot be reversed (Scaramuzzi et al., 2011).

While many spring-born heifers are developed from weaning to breeding in a dry-lot and fed a diet consisting of a combination of forage and concentrate feeds, based on research previously discussed, implementation of heifer development systems utilizing grazing have become more common. Previous studies evaluating the utilization of a stair-step nutritional program developed heifers in the drylot and failed to determine if the increase in the primordial follicle pool is possible in heifers developed grazing native range and supplemented to follow a stair-step nutritional scheme. Recently, researchers at New Mexico State University examined this, investigating if utilizing a stair-step nutritional strategy would slow activation of primordial follicles, increasing the size of the ovarian reserve in beef heifers regardless of whether they were developed in a drylot or grazing native range (Rosasco et al., 2020). Angus cross-bred heifers (n = 40) were utilized to determine the effect of a stair-step development system on fertility and ovarian dynamics. Heifers (11 months) were assigned to 1 of 4 treatments: 1) constant gain drylot (CG-d), 2) stair-step drylot (SS-d), 3) constant gain native range (CG-r), and 4) stair-step native range (SS-r). Heifers were fed individually with a constant gain target of 1.1 lb/d average daily gain, while stair-step heifers were targeted to gain 0.55 lb/d the first 45 day (period 1) and 1.65 lb/d over the last 45 day (period 2). Heifers developed grazing native range were individually supplemented three times per week. All heifers were ovariectomized at the end of the 90-day development period. Ovarian measurements were collected to assess difference in ovarian dynamics. Histology was performed on ovarian tissue to determine the number of microscopic follicles (primordial, primary, and secondary follicles) and evaluate the influence of dietary treatments.

Heifer body weight was similar at initiation of treatments. Heifers grazing native range had an increased body weight at day 45 and day 90 ($P < 0.01$) compared to drylot heifers. Overall average daily gain and average daily gain over the first 45 days was greater in native range heifers ($P < 0.01$) compared to drylot heifers. During the last 45 days CG-r and SS-r heifers had an increased average daily gain compared to CG-d and SS-d heifers, with SS-d also having an increased average daily gain ($P = 0.03$) compared to CG-d heifers. Lack of differences in performance among native range treatments may be attributed to the fact that supplementation often alters grazed forage intake and can decrease grazing selectivity (Krysl and Hess, 1993; Moore et al., 1999). The divergence in growth performance among drylot and native range developed heifers was a result of heifers being managed in the drylot, permitting nutrient intake to be strictly monitored and controlled. Additionally, performance of heifers grazing native range exceeded anticipated gains based on supplement and forage nutrient values. This is likely due to the natural ability of grazing ruminants to selectively graze, thereby increase diet quality.

Table 1 Ovarian characteristics of heifers raised in the drylot or on native range receiving either a constant gain or a stair-step diet (Rosasco et al., 2020).

	Drylot		Native range			*P*-value		
Item	CG[1]	SS[2]	CG[1]	SS[2]	SEM	Trt	Group	Trt x Group
Dominant follicle, mm	10.7[a]	11.1[a]	13.1[b]	14.4[b]	0.7	0.20	<0.01	0.46
Estradiol, ng/mL	153.0[a]	158.5[a]	439.1[ab]	531.2[b]	110.5	0.65	<0.01	0.69
Progesterone, ng/mL	219.3	115.6	219.3	462.4	123.1	0.57	0.16	0.16
Estradiol:Progesterone	5.5	2.0	4.5	2.3	1.7	0.10	0.86	0.69
Primordial follicles/section	35.9[a]	84.2[b]	69.9[ab]	84.4[b]	15.0	0.04	0.24	0.25

[a,b] Means within a row without a common superscript differ $P < 0.05$.
[1]CG = constant gain heifers targeted to gain 1.1 lb/d for 90d.
[2]SS = stair-step heifers targeted to gain 0.55 lb/d the first 45-days and 1.65 lb/d the last 45-days.

Dominant follicle diameter and concentrations of estradiol in the follicular fluid of the dominant follicle were increased ($P < 0.01$; Table 1) in native range heifers compared to drylot heifers. Follicular fluid progesterone concentrations and the estradiol:progesterone ratio, however, were similar among all treatments. The microenvironment within the dominant follicle, comprised of growth factors and steroid hormones, influences quality of the oocyte, directly impacting reproductive success. Follicular fluid estradiol concentrations can be an indicator of the ability of the oocyte to be fertilized, with an estradiol:progesterone ratio > 1 indicative of an estrogen active follicle (Sunderland et al., 1994). While increased concentrations of estradiol in native range heifers was likely driven by an increase in dominant follicle diameter, dominant follicle diameter has been reported to influence pregnancy success. Perry et al. (2007) observed heifers ovulating follicles ≥ 12.8 mm in diameter had increased pregnancy rates compared with heifers ovulating follicles < 10.7 mm in diameter. While all treatments had a dominant follicle diameter > 10.7 mm, increased dominant follicle diameter in heifers developed grazing native range suggests native range heifers would potentially have an increase in reproductive performance due to enhanced ovarian function. The potential improvement in ovarian function in heifers developed grazing native range compared to drylot developed heifers implies that reproductive success may have been enhanced due to difference in dietary treatment. This may be attributed to the increased average daily gain in native range heifers compared to drylot heifers during the last 45 days of the development period (1.09 lb/d vs 2.18 lb/d, respectively), providing a flushing effect in native range heifers.

Primordial follicles/histological section were increased (P = 0.04; Table 1) in SS-r and SS-d heifers compared to CG-d heifers, with CG-r similar to all other treatments. Utilization of a stair-step development program positively impacted primordial follicle numbers, increasing the size of the ovarian reserve, and potentially resulting in greater reproductive longevity. These results suggest mechanisms controlling primordial follicle activation may be slowed due to utilization of a stair-step compensatory growth program, however these mechanisms are not well understood. Similarities in primordial follicle numbers between CG-r and SS-r heifers suggests the constant gain diet in the drylot had a larger impact on mechanisms controlling primordial follicle activation, than in heifers on a constant gain diet grazing native range. Further research is already underway and focused on identifying mechanisms contributing to the influence of nutritional programming on the ovarian reserve. In a recent study by Freetly et al. (2021) authors reported heifers developed on a stair-step growth pattern had an increase in reproductive longevity and stayability. These results further suggest the increase in the size of the ovarian reserve in stair-step developed heifers, regardless of if they are managed in a drylot or grazing range, may potentially program fertility, resulting in an increase in reproductive longevity.

Influence of Heifer Development Systems on Cow Longevity

The interaction between nutrition and reproduction in heifer development has been well established, however, research regarding the mechanisms controlling the interaction and the impacts of heifer development systems on cow longevity is limited. The effect of post-weaning development strategies on cow longevity and lifetime productivity is complex as it can be influenced by the environment, nutritional status, and management practices utilized throughout the animal’s life. Heifers developed on restricted gain to 53% of mature body weight had similar pregnancy rates through the fourth calving season compared to heifers developed to 58% of mature body weight (Funston and Deutscher, 2004). Research comparing the effect of winter supplemental feed level on in herd retention and survivability revealed cows receiving the low level of nutritional supplementation appeared to have an improved average lifespan (14.65 year) compared to medium (13.07 year) and high (10.88 year) supplemented cows (Pinney et al., 1972). Additionally, Pinney et al. (1972) suggested that differences in survivability or longevity are established early in life. In a 10-year study, Hughes et al. (1978) suggested an advantage in retention rate for beef cows on a lower plane of nutrition compared to cows maintained on a greater plane of nutrition. Cows developed and maintained on a low or moderate plane of nutrition had a 77% retention rate compared to cows that were developed and maintained on a high or very high plane of nutrition that had a 63% retention rate. Heifer development systems that manage heifers in extensive systems may better prepare heifers for future production environments and positively impact survivability. Mulliniks et al. (2013) reported a greater retention rate through 5 years of age in range-developed heifers receiving a high-RUP supplement (68%) compared with range-developed counterparts fed a low-RUP supplement (41%) and heifers fed in the drylot (41%). These data indicate that where a heifer is managed during pre-breeding development (drylot vs. extensive), as well as specific nutrient content may influence survivability. It should be noted that differences among retention rates reported in current research can be influenced by specific culling criteria.

Heifer development systems focused on acclimation of heifers to extensive production environments may allow heifers to be better adapted and prepared for future challenges facing the grazing animal. Exposure and adaptation of animals to their grazing environment early in life may allow for animals to gain invaluable grazing experience and develop improved grazing behavior over the course of their life. Thus, heifers managed grazing in a range setting may be better adapted to their future production environment, which may improve animal performance and result in an increase in longevity compared to animals developed in intensive management systems (i.e., drylot or high rate of gain). Overall, studies evaluating the influence of heifer development systems on cow longevity are limited. Current research, however, suggests developing heifers to lighter target body weights and(or) grazing native range may allow for animals to be better adapted to their future nutritional environment and periods of negative energy balance experienced in many range settings (Endecott et al., 2013; Mulliniks et al., 2013; Summers et al., 2014). Understanding the demands of future production environments and the influence of management strategies used during development of heifers on performance and longevity must be considered when designing heifer development strategies. Longevity impacts producer sustainability and profitability; therefore, current and future economic implications of heifer development studies must be considered.

Implications

Nutritional management of heifers during the first year of life is critical in establishing the foundation for fertility, productivity, and longevity in a beef herd. Decisions made regarding nutritional management of heifers can help program puberty attainment, fertility, and the ovarian reserve potentially allowing for increases in reproductive performance and longevity, resulting in improved profitability. Development of replacement heifers on a stair-step nutritional program resulted in a larger ovarian reserve before the onset of the breeding season. A nutritionally mediated increase in the ovarian reserve could potentially have a positive impact on reproductive longevity, providing a viable management strategy for producers. Overall, identification of management strategies that effectively utilize resources, enhance reproduction and longevity, as well as allow adaptation of heifers to future production environments will provide producers additional opportunities for profitability and success in their operations.

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Identifying our Blind Spots in Calf Health: A Vet's Perspective

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Introduction

As we think about getting newborn calves off to a healthy start, I would like to share a few thoughts with you from my perspective as a cattle veterinarian. I'll start by taking you back in time about 100 years to look at an article by Charles Wood published by the Agriculture History Society on the Kansas experience with blackleg in calves and the successes they met with in dealing with it. I believe this story holds some lessons for us today in the way we view cattle health topics in general. We'll then move to disease prevention and a review of the Sandhills Calving System, and finish with some ideas on ways that together with your veterinarian, you can keep your focus on the most important factors related to keeping calves healthy.

Blackleg History

"Blackleg" is the name given to a disease that caused large numbers of calves to die a century ago across the western and southwestern US. It is present worldwide and was known, described, and documented as early as 1782 (4). The disease causes muscle necrosis, meaning death of muscle tissue. It often affected large numbers of calves at once, though young cows could be affected as well. Animals from 6-24 months of age are considered at highest risk. The disease causes lesions in muscle that are infiltrated by numerous gas bubbles and are dark red to black in color. It occurs most frequently in the shoulder and hip musculature of the animal. It develops when spores of the bacterium *Clostridium chauvoei,* which are often present in the soil, are ingested, cross the wall of the gastrointestinal tract, and are transported throughout the body and into the muscles, including the muscle tissue of the diaphragm and heart. These spores (think of these as bacterial "seeds") begin to grow vegetatively (which means into full-grown toxin-producing bacteria) when there is a lack of oxygenation in muscle tissues. An area of muscle bruising is one example of a time when oxygenation is low, and conditions are right for *Clostridium chauvoei* growth and blackleg disease. The disease often caused large numbers of cattle to die in a short time and could be economically devastating. In Kansas and throughout the western part of the United States in the early 1900's, blackleg was reported to have caused more losses than all other cattle diseases combined, as much as 5-25% of the annual calf crop according to an official with the US Bureau of Animal Industry, the predecessor to USDA (1). Outbreaks still occur worldwide, with recent reports of significant die-offs in Australia. Years with abnormally wet weather and dirt work in the cattle pens or pastures that disturbs soil are risk factors. Risk is also higher in areas that flood periodically.

Charles Wood records the treatments that were common prior to vaccination: slashing infected quarters and applying carbolic acid, tying a red ribbon through the dewlap, cutting off the tip of the tail, and other relics of folk medicine that were not effective. Over time, various vaccines were formulated and tried, with mixed results at first. One of the first was from Lyons, France, where the world's first veterinary school was founded in 1761. Sometimes heat-inactivated vaccines were too weak and didn't produce immunity, and sometimes they were not fully inactivated and produced outright blackleg disease. Soon, however, a vaccine was developed at Kansas State Agricultural College that both reliably prevented blackleg disease and was much less risky for the animal receiving the vaccine. Some of the filtering equipment needed to produce the vaccine was imported from Germany just before World War I began. Overall, the effectiveness of the "Kansas vaccine" was an astounding success story. An outbreak in a purebred herd in the Flint Hills with over 600 calves and an outbreak in a feedlot near Abilene were both apparently halted with the use of the new vaccine, and these high-profile successes helped other cattlemen trust the product enough to try it themselves. Calves receiving the vaccine didn't get sick, and immunity appeared to be life-long. R.R. Dykstra, a veterinarian at the Kansas State Agricultural Experiment Station, is quoted in the article as saying, "[The Kansas vaccine] was the outstanding product of the Experiment Station in its service to the people of Kansas and to all those engaged in livestock production (1)."

As you can see, a major early success was achieved in the beef industry in vaccinating for blackleg in calves. Wouldn't this dramatic success have left a lasting impression in the minds of the people involved? Those impressions and attitudes are passed down over time and become part of a culture. Now, after generations of vaccinating cattle for it, we see very little blackleg. In my career, I've only been involved with one case of it, in a single animal. My diagnosis in that case was based on visual postmortem examination only, and laboratory-confirmation was not pursued as only one animal was affected. Blackleg has become so rare that some veterinarians no longer include it in vaccination programs at feedlot entry or even in calfhood (3). I am not saying what you should or shouldn't use in your vaccination plans. That discussion is between you and your veterinarian and depends on the risk factors specific to the cattle and management system on your operation. I am pointing to broad changes within the industry over time to help us focus on the most effective methods of keeping calves healthy.

This look at blackleg history is to illustrate a success story in which a vaccination appears to have played a major role in causing what was once a costly disease to become rare to nonexistent across large segments of the beef industry in the US. Among most of the vaccines commonly in use in beef cattle, this is more of an exception than the general rule. Despite many vaccines against various BRD pathogens, neonatal calf scours, and other disease such as pinkeye (infectious bovine keratoconjunctivitis), those diseases continue to exist within beef herds at various production stages. This is not to say the vaccines are ineffective, just that they have not eliminated the diseases from the population. Of course, there are major differences between these diseases and blackleg. All the examples above are multi-pathogen diseases, and some of the pathogens are nearly always present in beef herds, and others are commensals, meaning organisms normally present in healthy animals. These commensal bacteria become virulent (disease-causing) when the animal undergoes stressful circumstances or is debilitated or sick. Granted, in a sense, this is an apples to oranges comparison. But, I believe the lesson is that our expectations for many of the vaccines we use today need to be different than what our forebearers may have expected from vaccines immediately following the blackleg success. So, we need to put vaccines in where they fit, but that cannot be where we stop. As Chris Chase, DVM PhD said at a recent conference, "Vaccination can never overcome poor management." There are opportunities for management factors to substantially improve our success in the fight against these and other bovine diseases, as we will discuss in a moment.

Before we move on, however, I also want us to consider to what extent such a dramatic early success with vaccination in beef cattle may have shaped how veterinarians have structured their businesses over the last century. I think it may have been substantial. We will touch on this again at the end.

The Sandhills Calving System, a method of scours prevention

Next, let's look at the Sandhills Calving System (SCS), which is a method of scours prevention, and the studies behind it. Judging from NAHMS data, I would guess that over 40% of the operations represented here (and possibly much higher, since your presence indicates that you are a group that pushes forward to learn and grow as cattle producers) already employ some version of the SCS, so we will review it quickly. The SCS developed from the realization that scours outbreaks often occurred when groups of calves were born in the same location, often muddy, over several months. The calves born later in the season were at many times higher risk of scours and death than the calves born first, and the idea developed as a way to restart calving season over and over in different pastures. It involves beginning the calving season with several clean pastures. Clean in this sense means that they have not had cattle on them for the previous few months. For the first two weeks, the cow herd is together in the first pasture. After calving has gone on for two weeks there, all the still-pregnant "heavy" cows are moved to the second calving pasture. The pairs from the first two weeks of calving remain in the first calving pasture. After another week to ten days, all the cows that have yet to calve are again moved to the third pasture, and the calves born on pasture two stay there with their mothers. After another week to ten days, all the heavy cows are moved ahead to the fourth pasture, and so on. This allows calves to be born onto clean pastures and allows cows to maintain clean udders as they are laying on clean surfaces. It prevents 3 to 4-week-old calves, which shed large volumes of viral and bacterial pathogens, from inundating the newborn calves with those germs. Calves are maintained in "age cohorts," meaning groups of calves that are within a week to ten days of each other in age. When the youngest calves are a month old, the group can be reassembled. This allows for calving to be effectively re-started numerous times and re-creates the generally healthy environmental conditions typically present at the beginning of calving season.

The following research data into the effectiveness of the SCS was presented in 2003 here at the Range Beef Cow Symposium, but it appears that it has been at least a decade since it has been revisited. I have been able to hear the story firsthand from the veterinarians that devised the SCS, and I'll explain it briefly now. In the early 2000's, University of Nebraska researchers worked with two main ranches. In the 3-5 years prior to implementing the SCS, the two ranches had been struggling with scours death losses ranging from 6-15% of calf crop year after year. It had caused significant stress, workload, and medicine expense and financial losses on both operations. Both ranches decided to give the new idea a try and mapped out how they would make the necessary pasture moves. As calving began and the weeks went by, veterinarians involved waited to see if the new plan would work. Finally, the suspense prevailed, and a call was made to the local veterinary clinic to check on the ranches and see how calving season was going. On one of the ranches, the rancher's wife oversaw sick calf care. She was almost never in town during calving season because for years the workload had been too heavy. The news was relayed to researchers from the veterinary clinic that someone had just seen her in town getting her hair done, right in the middle of calving season! That year, and until the end of a three-year follow-up, neither of the ranches that tried Sandhills Calving lost a *single calf* to scours, and never treated more than three. The ranchers commented, "We no longer "pair-out," now we "heavy-out!" Sandhills Calving is another major success story within beef cattle veterinary medicine, arguably one of the biggest management advances to promote animal health in the last 20 years.

How veterinary services are provided

Now, let's revisit the question of veterinary practice models and consider how the way that they are often structured affects the emphasis on a SCS type of intervention.

At the cow/calf level, our traditional model of veterinary service delivery is that veterinarians are paid for selling pharmaceutical products like vaccines and antibiotics, and for providing services like pregnancy checking, semen testing bulls, processing calves, and treating individual animals that are sick or injured. There are currently not widespread practice models among cow/calf veterinarians in which they are paid directly to help producers optimize the production system to improve animal health. These models exist at the feedlot level, but not generally for cow/calf operations. But cow/calf veterinarians often do help with optimizing management systems, don't they? When they do, they are usually doing so at their own expense, essentially "volunteering" those services to help you to be successful long-term and to retain your business for the services above and the pharmaceutical sales. They do this in large part because this is what they're passionate about, and what they promised to do in the veterinary oath. They often convey information, such as the SCS, that will actually hurt their bottom line in the short term. They do this because it is in the best interests of their clients and their clients' animals. But how much better could they do if they were directly incentivized to do it? Wouldn't you rather have these professionals more sharply focused on helping you optimize cattle health? What might they think of that could unlock significant operational advances for you, the way the SCS practically eradicates scours with a few carefully planned pasture moves? Wouldn't you rather have them educating you on what the most common barriers in implementing the Sandhills Calving System are, and how to overcome them? Educating you on what a BVDV PI calf is, and how to prevent them from being born persistently infected? On what types of preparations are most cost-effective to reduce the likelihood of cattle losses due to weather events? Wouldn't you want them training you on what the most common toxic plants are in your area that could be harmful to cattle, or the most common accidental poisoning situations? These are just a few examples of ways I believe veterinarians can use their educations to best aid cow/calf operations, rather than focusing the lion's share of our time and energy on "bugs and drugs," as we traditionally have. An ounce of prevention is truly worth a pound of cure. If these ideas sound worthwhile to you, ask your veterinarian if he or she is thinking about offering any system-optimizing consulting services, and if so, what form they may take. Who knows what you might discover?

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EMERGING DISEASE: CONGESTIVE HEART FAILURE IN FED CATTLE

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Summary and Implications

Congestive heart failure in feedlot cattle is a fatal outcome that can be generated by several disease processes. Recently, congestive heart failure has been diagnosed with increasing frequency in feedlot cattle without accompanying evidence of a direct cause. A review of the literature reveals similar cases being described as early as the 1970s; however, recent epidemiologic evidence indicates the frequency of this version of congestive heart failure is increasing in populations of fed cattle in North America.

Our research group has approached this novel form of congestive heart failure by describing the frequency and distribution of cases in Nebraska feedlots and by conducting an investigation to uncover genetic risk factors for congestive heart failure. These proceedings will provide an overview of our findings to date.

The implications of our work support previous work demonstrating an increasing frequency in feedlot cattle, particularly in western Nebraska feedlots. Further, our data indicate that congestive heart failure is not only a problem of late-fed cattle. Rather, cases can occur at any point during the feeding period. Our investigation into genetic risk factors has eliminated a previously proposed risk factor for congestive heart failure that occurs in cattle at high elevations as a contributor to the heart failure observed in cattle fed at lower elevation. A genome-wide association study revealed several potential risk factors that are currently being validated for use in selecting cattle with lower genetic risk for congestive heart failure.

Introduction

Congestive heart failure of cattle is a consistently fatal outcome of several disease processes. In general, diseases that create increased resistance to blood flow or that compromise the pumping activity of the heart itself eventually manifest as heart failure. Because the heart has two pumping chambers (ventricles) that are used to pump blood to both the lungs and out to the body simultaneously, the symptoms of heart failure depend on which chambers are affected by the disease. There are three basic disease processes that lead to heart failure in cattle. The first is an inability of the heart to completely fill with blood when it is resting in preparation for the next heartbeat. In these cases, the heart cannot pump enough blood to meet the metabolic needs of the body, nor can it pump blood away from the body fast enough to prevent the buildup of fluid in the body. The process is responsible for heart failure cases caused by hardware disease or cancer that fills the space around the heart (usually lymphoma). Another process that leads to heart failure is when the heart itself is damaged and cannot pump effectively. Heart damage is the process involved in ionophore poisoning and *Histophilus somni* infections that damage the heart muscle itself. The third process that leads to heart failure is resistance to blood flow that overloads the heart and eventually causes the heart to be unable to maintain blood flow. Examples of this process include resistance to blood flow through the lungs of cattle that are exposed to low-oxygen environments like those found at high elevations (>5,000 feet) and in calves that have chronic pneumonia.

In recent years, feedlot producers in areas of moderate elevation (approximately 3,000-5,000 feet) have noted an increasing number of heart failure cases in which a cause was not readily apparent. Early impressions of these cases were that they tended to occur primarily late in the feeding period. Speculation about causes was varied and included proposed mechanism related to heart/lung capacity, rapid growth, degree of fatness/obesity, and chronic outcomes of prior respiratory disease. One consistent observation among these cases was that they tended to arise from the same sources of cattle over time, strongly suggesting that a genetic factor might be involved.

Epidemiologic Characteristics

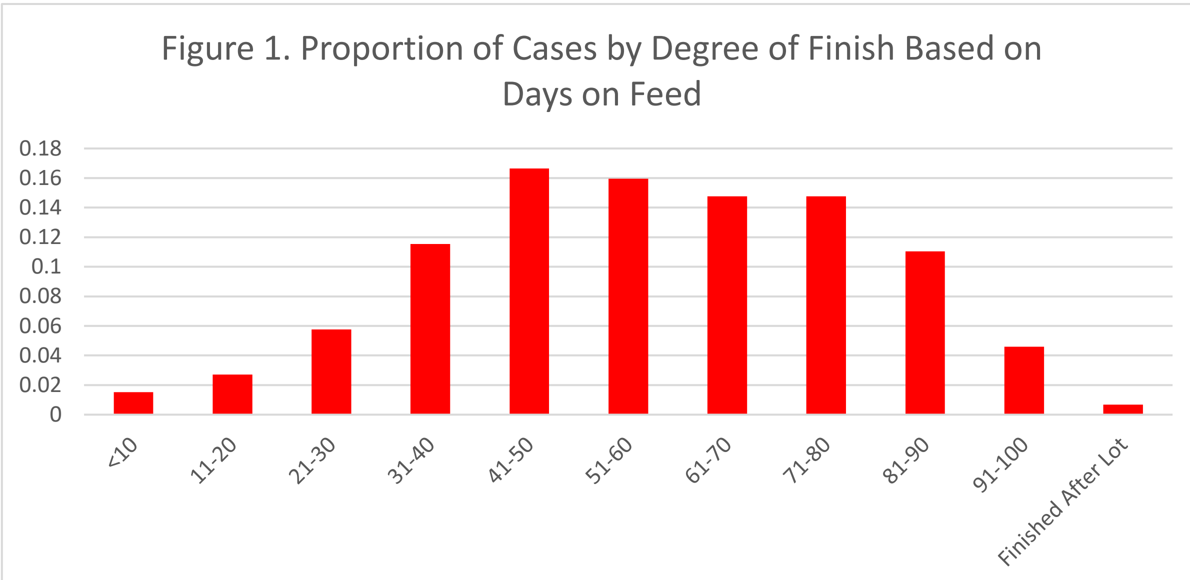
For the purposes of these proceedings, bovine congestive heart failure (BCHF) will be used as a term to describe the heart failure being observed in feedlot cattle. One objective of our research group is to describe the epidemiologic characteristics of BCHF to facility discovery and validation of risk factors contributing to this disease. Epidemiologic characteristics of interest include the overall frequency of disease among and within feedlots, the frequency of lots affected with at least one case, and the number of cases that occur within lots.

A study published by Neary et al. examining frequency of heart failure in 1.56 million feedlot cattle from 2000-2012 showed that heart failure deaths approximately doubled over the study period with 11 calves dying from heart failure for every 10,000 calves placed (Neary et al., 2016). We collected data from 1,361 lots composed of 151,401cattle over a 6-year time frame to evaluate the frequency of heart failure in a more localized population. In this dataset, there were 600 presumed BCHF cases (0.4%, 39 cases/10,000 head placed). Table 1 shows the frequency of lots with varying numbers of cases. This table demonstrates that the vast majority (83%) of lots have no BCHF cases, but that a few lots are severely affected. Cases were seen in all months of the year with the highest frequency occurring in the first 5 months. Cases were also diagnosed throughout the feeding period. Evaluation of case timing relative to the feeding period is useful to identify potential management factors that drive risk; however, simply looking at days on feed disregards the total time at risk. Case frequency was plotted by days prior to cohort harvest, but this approach failed to account for time at risk as well.

Table 1.

Cases /Lot	*Frequency*
0	1125
1	130
2	47
3	21
4	14
5	6
6	4
7	1
8	2
9	2
10	0
More	9

To solve this, cases were plotted based on frequency by degree of finish, which was defined as the percentage of time elapsed by the time of diagnosis compared to the total feeding period of the lot (e.g. a calf diagnosed on day 50 in a lot that finished in 200 days would be classified as 25% finished). A plot of the proportion of cases by decile of percent finished is presented in figure 1. This figure demonstrates that cases occur throughout the feeding period with increasing frequency with cattle reaching at least 30% finished.



The most notable epidemiologic characteristics of BCHF cases in our investigation were the clustering within sources over years and the distribution of cases throughout the feeding period. The clustering affect strongly indicates a genetic component of disease, especially because most of the cattle in severely affected lots remained healthy and finished successfully. The distribution of cases indicates metabolic load and/or fat deposition are not sufficient explanations for the frequency of cases earlier in the feeding period.

Genetic Risk Factors

Observational evidence of a genetic component to BCHF was strong. Newman, et al. reported as association between *EPAS1* and heart failure at high elevations (Newman et al., 2015). To test the hypothesis that *EPAS1* might also contribute to BCHF as well as to identify other potential risk factors, a case/control study was conducted. In this study, large populations of feedlot cattle were screened by caretakers to identify suspect cases of BCHF. Following identification, suspect cases were euthanized and examined to confirm heart failure and identify potential causes. Animals with known causes of heart failure were excluded from the study. Tissue was collected from confirmed cases as well as from a control from the same pen and of the same coat color and gender. A total of 102 match pairs were generated. These animals were genotyped for *EPAS1* variants. No association between *EPAS1* and BCHF was discovered (Heaton et al., 2019). DNA from each case and control was then used in a Genome-Wide Association Study (GWAS) based on 770k HD Beadchips (Illumina) to identify other potential genetic risk factors by identifying and comparing differences between matched cases and controls. Using this approach resulted in the discover of 21 potential genetic risk factors. Two of these risk factors, association with *NF1A-AS2* and *ARRDC3* (BCHF2 and BCHF5, respectively) increased the odds of disease by 15 times in cattle with both risk factors compared to cattle that had neither. These two risk factors have been validated in an independent population and commercial tests are currently available for cattle. Evaluation of the impact of genotyping and selecting based on these two genetic factors is underway. For more information and resources related to BCHF visit https://www.ars.usda.gov/plains-area/clay-center-ne/marc/bchf/bchf-main/.

Summary

Characterization of risk factors, genetic and otherwise, is ongoing for BCHF. Two risk factors have been discovered and show potential as tools to select breeding animals to produce less risk of BCHF in their offspring; however, research validating this approach has not yet been completed.

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