Bull Development and Nutrition: Fertility and Beyond

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Introduction

To maximize reproductive efficiency in their herds, beef producers pay close attention to nutritional and other managerial inputs. Following suit, many research efforts throughout the world have focused on aspects of managing breeding females. Substantially less science-based information is available, however, regarding the nutritional management of bulls. The United States beef industry is dominated by herds that rely solely on bull breeding. The percentage of operations that relied only on bull breeding was 95.5% and of beef cows maintained, 98.4% were at least exposed to a bull during the breeding season (NAHMS 2020).

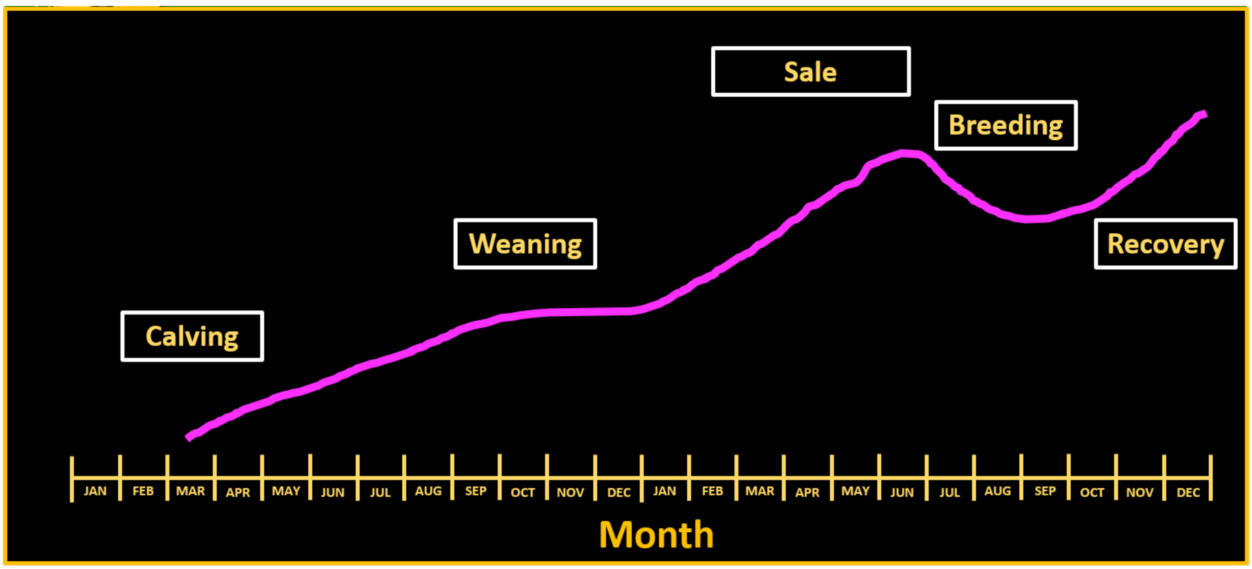

Figure 1. Schematic of bull body weight and key developmental milestones over the first 2 years of life.

Over the course of a bull's life and even within a year in his life, dramatic and dynamic changes in body weight and plane of nutrition are occurring (Figure 1). The pre-weaning, post-weaning, and post-breeding periods each present unique periods of potential management intervention. In addition, effects of relatively short-term feeding decisions (i.e. how should I feed my bulls today) may have long-terms impacts that extend to their offspring.

Pre-Weaning Period.

During the pre-weaning period young bulls are managed with their dams; suckling milk and grazing the same pastures or consuming the same stored feeds as their dams. Though everything may look tranquil at this time there are major transitions occurring in the developing testicles that will have lifelong impacts on future sperm production. The period from 1 to 5 months is when seemingly subtle hormonal signals are responsible for proliferation of the Sertoli cell population. Sertoli cells are important because

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there is a maximal number of developing sperm cells that each Sertoli cell will be able to protect and nourish later in life. The population of Sertoli cells is set by 5 months of age, but the more Sertoli cells found in the testis the greater the potential daily sperm production as an adult (Berndtson et al., 1987).

Nutrition before 6 months of age is likely the most important influence of future sperm production potential. Research in both beef and dairy bulls has found that enhancing early life nutrition can result in enhanced Sertoli cells populations, testicle size, and sperm production along with a reduced age at puberty (Brito et al., 2007; Brito et al., 2012; English et al., 2018; Kenny and Byrne, 2018). It is also important to note that negative effects of nutritional deficiencies experienced before puberty cannot be overcome by enhancing nutrition after weaning (Thundathil et al., 2016).

From a practical standpoint we need to avoid nutritional deficiencies when possible and consider options for enhancing plane of nutrition when practical. Bulls born from cows had larger scrotal circumference than bulls from heifer dams (Lunstra et al., 1988), likely due to the greater milk production in cows leading to greater bull body weight. Cases of poor pasture quality or availability put further nutritional strain on developing bulls and may need to be mitigated. Providing creep feed is a way to enhance pre-weaning nutrient delivery to bulls that may be practical, but heifer calves receiving excess creep feed could have reduced future milk production (Buskirk et al., 1996). If multiple pasture cells and associated labor are available there may be merit in dividing pastures by calf sex and applying sex-specific targeted management. If cooperator herd are being used as embryo transfer recipients of sale bulls be sure to choose multiparous cows with a good history of mothering ability and milk production.

Post-Weaning Period.

Post-weaning development strategies vary among producers with some raising bulls to gain at aggressive rates whereas others prefer a moderate gain approach. Gains from 2.2 to 3.5 lb/day were reported to be "safe" targets for bull development from 6 to 16 months of age (Brito et al., 2012) but a quick look at bull test reports or sale catalogs will show some bulls growing faster than 5 lb/day. For normal sperm development testicular temperature needs to be maintained 4 to 6 ° cooler than body temperature. High grain diets have been shown to increase scrotal fat and temperature temperature (Bourgon et al., 2018), leading to and increased proportion of sperm with morphological abnormalities, and overall reduced motility.

Genetics and growth potential of specific bulls play a large role in gain that can be achieved and bulls need to be managed to ensure they are putting on weight as muscle and not excess fat. We have completed that first year of a 3-year effort comparing growth rates of 2.5 and 4.0 lb/day in Balancer bulls and have not observed any alterations in sperm properties (Crouse et al., unpublished).

An example of reproductive characteristics during the bull development period is found in Table 1. The 36 bulls used in this example were all embryo transfer calves from a single sire gestated and mothered by multiparous crossbred Angus cows. Average birthweight was 85 lb and bulls gained 2.7 lb per day while suckling. No management interventions (creep feed, etc.) were in place to provide extra nutrients during the pre-weaning period and weaning weight averaged 610 lb. After weaning we targeted a gain of 3.5 lb per day for 112 days. By 9 months of age a portion of the bulls were already pubertal, and all bulls had reached puberty and were classified as satisfactory breeders by the age of 13 months.

Table 1. Reproductive characteristics of yearling Angus bulls during development							
	Bull age in Months[2]						
Item	**9**	**10**	**11**	**12**	**13**	SEM	*P*-Value
Body weight, lb	705	778	896	1006	1101	9.24	<0.01
Scrotal circumference, cm	30.0	32.0	34.5	35.7	36.8	0.26	< 0.01
Ejaculate volume, mL	2.0	4.3	7.2	7.8	8.0	0.5	< 0.01
Concentration, million/mL	32.0	56.0	73.4	124.5	115.6	14.4	< 0.01
Total sperm, million	68	277	536	1048	937	142	< 0.01
Pubertal, %	22.2	72.2	88.8	94.4	100.0	0.05	<0.01
Motile, %	28.4	51.9	57.5	58.7	72.7	3.5	< 0.01
Progressive, %	9.0	39.9	46.6	47.6	61.5	3.1	< 0.01
Slow, %	3.6	6.2	3.6	7.0	2.6	2.0	0.36
Static, %	55.7	36.6	41.3	40.8	27.3	3.8	< 0.01
Morphology							
Proximal droplet, %	12.8	6.2	4.4	4.2	3.5	1.1	< 0.01
Bent tail, %	8.2	7.5	5.4	3.5	3.0	1.6	0.07

After a development period bulls are often sold. During the time of transition to a different environment and different diets bulls can lose a significant amount of weight. A Canadian study found that bulls lost an average of 2.6 to 4.8 lb per day (depending on breed) for 45 to 50 days after a sale (Barth et al., 1995). Recommendations for transitioning bulls to new environments toward breeding season include acclimating to forage, exercising on pastures, and targeting gain according to desired trajectory (Walker et al, 2009).

Breeding and Post-Breeding Periods.

Before being turned out to breeding pastures every bull should receive a breeding soundness exam (BSE; Koziol and Armstrong 2018). A BSE will evaluate semen and a bulls' physical characteristics (eyes, teeth, feet and legs, accessory sex glands) to determine suitability for breeding. Once a BSE is passed (or an alternative bull is identified), bulls can be turned out to pastured and monitored to ensure they are actively seeking and successfully breeding cows. During the breeding season bulls can experience dramatic weight loss; between 100 to 400 lb (Boyles et al., 2011; Walker et al., 2009; Hersom and Thrift, 2008). Continue close monitoring during the breeding season and be ready to replace injured or overly-fatigued bulls. Bulls losing weight during breeding season must be managed to regain the weight lost during the breeding season (Barth 2013), and sufficient nutrients need to be delivered to account for additional body growth. We monitored a group of bulls and saw continued weight increase as bulls matured from 1500 lb. at 2 years of age to 1750 lb. at 3 years of age to 1870 lb. at 4 years of age (Dahlen et all, unpublished)

Producer decisions determine the point at which bulls begin losing and gaining weight relative to the breeding season (Figure 2). In some scenarios, bulls begin losing weight only after being placed with females in breeding pastures. These bulls are then managed to gain weight, reaching targeted weight just before the subsequent breeding season. Bulls in this scenario would be in a **positive plane of nutrition** over the time course of sperm development (spermatogenesis). In an alternative scenario bulls may start losing weight before the breeding season. Perhaps these bulls experienced a recent change in environment and diet after purchase, or perhaps they were managed to gain weight over winter and needed to be cut back to get into "breeding shape" ahead of the breeding season. In either instance, these bulls would be on a **negative plane of nutrition** leading up to the breeding season. When we evaluate these two common production scenarios together we see a major divergence in plane of nutrition leading up to the breeding season.

Spermatogenesis in a continual process that takes roughly 61 d for sperm development, followed by up to 14 d residence in the epididymis prior to ejaculation. The net result is that sperm used to inseminate a cow today likely began the process of development up to 75 d before. Thus, divergence in plane of nutrition likely exposes sperm to different hormonal profiles and metabolic substrates during the time of spermatogenesis, residence in the epididymis, and upon combination with seminal plasma at ejaculation. The consequences of sperm development in these differing metabolic states resulting from divergent nutrition remain underexplored.

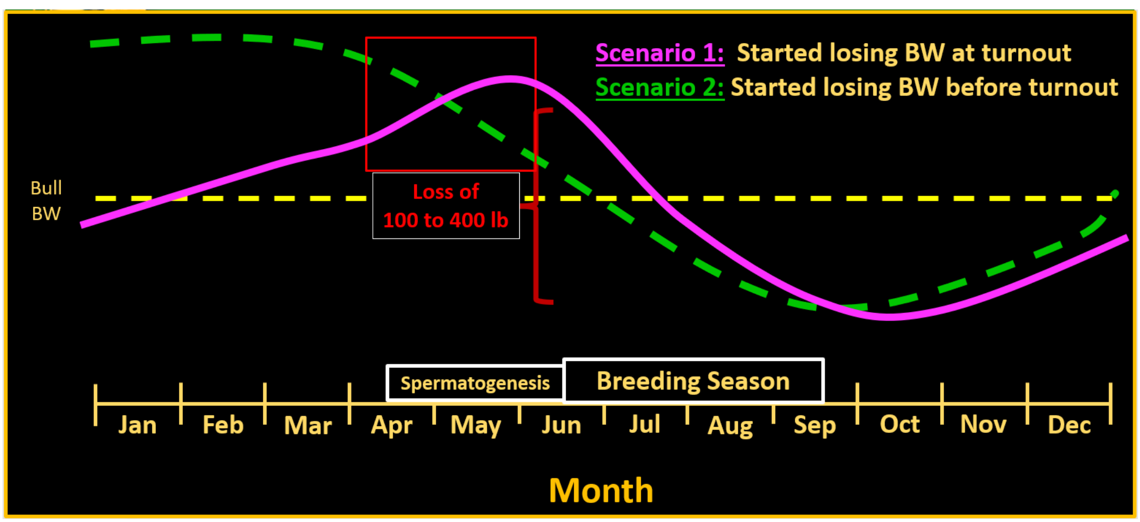

Figure 2. Body weight fluctuations of mature bulls over the course of a year. Figure depicts common production scenarios that result in different planes of nutrition during sperm development.

The Unknown: Does Nutrition During Sperm Development Impact Future Offspring?

The concept of developmental programming is that post-natal physiology is dictated, in part, by pre-natal factors such as maternal metabolism and other environmental factors (Barker and Clark, 1997). While the first evidence of programming effects were observed in humans during periods of major food shortages (Schulz, 2010), research in livestock species has revealed that maternal nutrition and management can impact offspring growth and performance (Caton et al., 2019; Dahlen et al., 2021). However, these studies and those of many other researchers have been confined to evaluations of the impact that dam management has on her offspring.

Research efforts in other species have shown that messages carried in a sires' semen after exposure to alcohol, drugs, or an obese state result in altered offspring development (Baber and Koren, 2015; Fullston et al., 2017). Impacts of sire obesity can be long lasting with differences observed all the way out to post-pubertal semen development in male offspring (Fullston et al., 2015). In addition, low protein diets fed to male mice altered offspring gene expression, resulting in heavier offspring with lower bone density compared with offspring from sires fed adequate protein (Watkins et al., 2017). However, paternal programming effects haven't been extensively studied or characterized in our livestock species.

One of the long-term goals of our research group is to determine the impacts of divergent bull nutrition on indicators of fertility and offspring outcomes. To date we have imposed treatments where bulls were managed on a positive or negative plane of nutrition (targeting a gain or lose 12.5% of their original body weight) for a 112-day period. This project was repeated over 2 years to allow for collection of a portfolio of samples from each individual bull in both a positive and negative plane of nutrition. Semen was collected on the last day of the experiment each year and cryopreserved for further analysis and breeding.

Any specific changes observed in semen and offspring are likely driven through epigenetic changes in sperm as a result of sire nutrition or management (Teperek et al., 2016). When we evaluated sperm for changes in sperm gene expression we saw differential expression of 769 genes (Diniz et al., unpublished) with a portion of differentially expressed genes being related to epigenetic mechanisms. These results indicate that plane of nutrition during spermatogenesis is altering messages in sperm that could influence fertility and also be delivered with the sperm at the time of fertilization. Messages delivered at the time of fertilization could subsequently influence growth and development of the resulting calf crop.

Our future efforts in this area include evaluation of *in vitro* fertilization rates and pregnancy rates in females after artificial insemination. Once calves are born we will evaluate their growth, metabolism, and reproductive responses. In addition, continued evaluation of these F1 calves through their reproductive stages will produce F2 generation offspring that will provide insight into whether any multigenerational effects of divergent sire nutrition are observed.

Summary

Early-life nutrition is extremely important to set the stage for timing of puberty and future sperm production. In cases where nutrient deficiencies are anticipated active steps should be taken to enhance nutrients available to pre-weaning calves. Post-weaning growth should be monitored closely to allow for adequate growth without excess fat accumulation. Monitor bulls closely during the breeding season to identify injuries and ensure bulls are actively breeding. Manage bulls to regain lost condition after the breeding season and allow for additional growth in younger bulls. Implications of specific timing and patterns of body weight gain on sperm characteristics and offspring outcomes are currently unknown but offer an exciting avenue for future discovery.

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