Developmental programming in beef cattle:

Impacts of gestational nutrition on calf growth and carcass quality

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D.W. Shike, L.M. Shoup, T.B. Wilson

The Fetal Programming Concept

The concept that maternal nutrition can have lasting effects on subsequent progeny performance is known as fetal programming (FP). This concept is based off of the principle that living creatures are plastic in their development and stimuli at certain points during development can cause permanent changes in body structure, function, or metabolism (Barker, 2012). The fetus is reliant on the flow of nutrients it receives from its dam through the placental membranes. Hence, the maternal environment is responsible for "programming" the growing and developing fetus for postnatal life. The concept was observed in human cohort studies, which showed a greater correlation in chronic disease and adverse maternal conditions, such as poor living conditions and food shortage, experienced by affected offspring in utero (Barker, 2007).

Nutrient Partitioning

Fetal growth trajectory is determined at time of conception by placental size and resulting ability to transfer nutrients across placental membranes, directly affecting birth BW (Vonnahme et al., 2007; Barker, 2012). A hierarchy of nutrient partitioning towards fetal growth and development exists. If maternal nutrient flow to the fetus is compromised, development of certain bodily systems takes precedence for nutrient partitioning over others. An extreme example of the hierarchy of nutrient partitioning is a phenomenon known as intrauterine growth restriction (IUGR). Wu et al. (2006) defines IUGR as impaired growth and development of the mammalian embryo/fetus or its organs during pregnancy. Severe nutrient restriction during gestation is a common cause of IUGR in livestock production. The need for adequate cow nutrition is brought into focus when considering that tissues of greatest economic performance, muscles and adipose, are of low priority during fetal growth and development.

Placental development in early gestation

The importance of proper nutrition during early gestation is often overlooked as cow nutrient requirements are much lower during early gestation relative to late gestation. Early gestation is of great importance because development of the placenta facilitates maternal nutrient flow for further growth and development to occur. Long et al. (2009) and Vonnahme et al. (2007) conducted studies that evaluated nutrient restriction of beef cows during early gestation (100% NRC requirements versus 68.1% of NEm and 86.7% of MP requirements). Both studies found negative affects on placental development and the developing fetus; however, some effects may be masked if nutrition is improved later in gestation.

Skeletal muscle and adipose tissue development

Development of skeletal muscle is of obvious importance to beef cattle production; yet, is of lower priority for maternal nutrient partitioning than organs or systems like the brain and central nervous system. Thus, risk of inhibited development of skeletal muscle is greater during periods of nutrient restriction. No net increase in muscle fiber number, hyperplasia, occurs following parturition, making proper development of fetal skeletal muscle extremely important (Du et al., 2010). Greenwood et al. (2004) reported that progeny born to nutrient restricted cows had reduced BW and HCW relative to those born to adequately fed cows. These differences were attributed to reduced muscle mass as a consequence of maternal nutrient restriction. Nutrient restriction lasting from early to mid-gestation has caused alterations in muscle fiber type, with type two, oxidative fiber types being favored in lambs (Zhu et al., 2006). Altering myofiber type has potential implications on postnatal muscle growth, growth efficiencies, and carcass characteristics later in life.

Development of marbling, or intramuscular fat, is of great economic importance to the beef industry. Intramuscular adipocytes are formed during fetal development and determine future marbling potential. To realize maximum postnatal marbling potential, multipotent cells must be committed to adipocyte formation in utero because few undifferentiated cells exist post-parturition. Adipogenesis is initiated approximately the fourth month of gestation, partially overlapping with the second wave of myogenesis. Management or nutritional strategies to increase adipogensis of the progeny in utero have yet to be refined. To preserve marbling potential of progeny, Funston et al. (2010a) proposed that ideal management would allow cows to achieve adequate body condition prior to exposure to conditions in which nutrients are limited. Strategies to achieve this include early weaning or altering time of breeding and subsequent parturition to avoid nutrient restriction during mid-gestation.

Plane of nutrition- nutrient restriction

Effects of severe maternal restriction during early to mid-gestation on subsequent progeny has been studied using both sheep and beef models. Ford et al. (2007) fed ewes to 100% of NRC (1985) requirement or restricted ewes to 50% of NRC requirement from d 28 to 78 of gestation. Previous literature (Vonnahme et al., 2003) indicated that this would induce IUGR but wether progeny birth weights were similar among dam treatment. Wethers born to nutrient-restricted dams also were heavier, had an increased backfat at 4 months of age, and appeared to be insulin resistant at 63 d of age compared to wethers born to adequately-fed dams. However, the same results were not observed when mature cows were restricted to 70% of requirement

(Long et al., 2012a) or 55% energy/50% CP requirement (Long et al., 2010a). Calves born to mature cows that were nutrient restricted did not differ in body weight at birth, weaning or slaughter but did have a greater adipocyte diameter than progeny of requirement-fed dams (Long et al., 2012a) and a reduced muscle fiber area in the complexus muscle of the steer progeny (Long et al., 2010a). The work of Long et al. (2010a) and Long et al. (2012a) show that nutrient restriction during early to mid-gestation does not automatically lead to obvious changes in growth rate of progeny, but can lead to more subtle differences in body composition.

Plane of nutrition- overfeeding

Interest in effects of maternal obesity on FP has grown due to an obesity epidemic in human populations. Extreme maternal obesity tends to be less common in livestock production due to the economic implications of maintaining animals in obese body condition. Several studies have evaluated the effects of overfeeding on subsequent progeny in both cattle and sheep. In two separate studies, Long et al. (2010b) and Long et al. (2012b) fed ewes 100% or 150% of NRC (1985) requirements 60 d prior to breeding through parturition and evaluated growth, body composition, maternal and fetal blood metabolites, and fetal adiposity. Maternal obesity resulted in phenotypic differences such as increased feed intake, a tendency to gain more weight, increased percentage of body fat, increased leptin concentrations, and increased insulin resistance than progeny born to ewes fed 100% NRC requirements (Long et al., 2010b). Ewes fed 150% of NRC requirements also bore progeny with differing adipose depots, fatty acid profiles, and fetal hormone concentrations such as plasma cortisol, insulin-like growth factor 1 (IGF-1), and thyroxine compared to progeny of ewes fed 100% NRC requirements (Long et al., 2012b).

Several overfeeding studies have been conducted in cattle that followed progeny through weaning or beyond. In Arnett et al. (1971) and Shoup et al. (2015a), mature cows were overfed supplement to result in divergent nutrient statuses of the dams during late gestation. In both studies, calf birth weight and weaning weight were not affected by treatment. However, Hughes et al. (1978) fed 8-mo-old Hereford females (n = 120) Low, Moderate, High, and Very High levels of supplement over 10 winters and found reduced birth weights in calves born to cows fed Very High levels of supplement in year 3 as well as reduced calf weaning weight in calves from cows fed Very High levels of supplement in year 5. These results indicate that obese fetal environment has the potential to restrict fetal growth and may also reduce post-natal growth via reduced milk production due to the large deposits of udder fat found in obese cows (Arnett et al., 1971).

Gunn et al. (2014) also overfed dietary CP during late gestation, although in a drylot setting. Calves born to dams fed excessive CP had a greater weaning BW despite no differences in milk production. Female progeny from dams fed excessive CP also had a tendency to have a greater BW and greater frame size, as well as improved AI conception (Gunn et al., 2015). Overfeeding, even of a specific nutrient, can have long term effects on performance and reproduction of progeny.

Grazing systems and fetal programming

Much of the previous research that has investigated the potential FP effects of maternal nutrition has analyzed only certain portions of the beef production cycle or has used nonruminant models. The number of studies that have investigated FP effects of maternal nutrition in the context of applied beef production systems are much more limited. Stalker et al. (2006) and Larson et al. (2009) conducted separate three year experiments that evaluated the effects of CP supplementation on cow and pre-weaning progeny performance as well as post-weaning performance and carcass characteristics of steer progeny. Stalker et al. (2006) offered cows wintered on native range pastures the equivalent of 0.45 kg of 42% CP supplement/cow·d-1 fed 3 d per wk or no supplement 90 d prior to the start of the calving season. Larson et al. (2009) investigated the influences of winter grazing system and protein supplementation on performance of both cows and subsequent progeny. Treatments were arranged in a 2 x 2 factorial in which cows were grazed on winter range or corn residue and offered the equivalent of 0.45 kg of 28% CP supplement/cow·d-1 fed 3 d per wk or no supplement 90 d prior to the start of the calving season. Results from both studies found no differences in calf birth BW but an improved weaning BW was observed in progeny born to protein-supplemented dams (Stalker et al., 2006). Additionally, Larson et al. (2009) observed effects in the feedlot where steers born to supplemented dams tended to have greater ADG and DMI, less treatments for respiratory and gastrointestinal disease, and greater marbling scores. This marbling difference indicates that improved maternal nutrition during late gestation can alter adiposity of skeletal muscle of subsequent progeny. However, improved maternal nutrition does not consistently result in altered intramuscular adiposity in progeny as Stalker et al. (2006) and Shoup et al. (2015b) found no differences in marbling at slaughter. This could be due to several reasons which include the differences in post-weaning health in Larson et al. (2009), varying RUP content of the supplement used between Larson et al. (2009) and Stalker et al. (2006), and the adequate body condition of all cows used in Shoup et al. (2015a).

Improved grazing during mid and late gestation

Although nutrient requirements of the dam are reduced in mid gestation compared to late gestation, it has firmly been established that that maternal nutrition during mid-gestation has great influence on fetal development (Du et al., 2010; Funston et al., 2010a). Underwood et al. (2010) conducted an experiment that investigated the influence of grazing cows on improved pastures during mid- to late gestation on the growth and carcass characteristics of resulting steer progeny. Beginning at either d 120 or 150 of gestation, mature cows were grazed on either native range (6.5% to 5.4% CP) or irrigated, improved pastures (11.1% to 6.0% CP) for a period of 60 d. No differences in steer birth or weaning BW were observed but, in the feedlot, steer ADG, HCW, subcutaneous fat, and tenderness were improved in steers born to dams grazing improved pastures. An improvement in pasture quality in late gestation was also evaluated in Shoup et al. (2016b) where cows either grazed toxic endophyte-infected fescue or non-toxic endophyte-infected fescue. Contrary to the results of Underwood et al. (2010), subsequent feedlot and carcass performance of progeny did not differ between treatments. It appears that the dam is more successful at shielding the fetus from a toxic nutritional insult than from variations in pasture nutrient quality.

Source of energy

Several studies have evaluated FP effects of source of energy in drylot diets fed to gestating beef cows. Radunz et al. (2010) and Radunz et al. (2011a) investigated the effects of feeding isocaloric diets consisting of ad libitum hay or haylage, limit-fed corn, or limit-fed DDGS from mid-gestation through parturition on dam and progeny preweaning performance in beef cattle and sheep, respectively. Calf birth BW was greater for calves born to dams fed DDGS or corn when compared to those fed born to dams fed hay (Radunz et al., 2010; Radunz et al., 2012). Lamb birth BW tended to be greater for lambs born to dams fed corn or DDGS when compared to those from dams fed haylage (Radunz et al., 2011a). When beef and sheep progeny were evaluated at finishing, carcass characteristics were similar except calves born to dams fed hay had greater marbling scores when compared to those fed corn, with those born to dams fed DDGS being intermediate and not differing from either (Radunz et al., 2012). Dressing percentage was reduced in lambs born to DDGS-fed ewes due to their greater kidney and pelvic fat than the other treatments (Radunz et al., 2011b).

Conclusions

Cow/calf producers manage herds in such a way that management of feed costs is balanced with maintaining acceptable cow performance. Acceptable performance is typically characterized by maintenance of BW and BCS, adequate milk production, and a 12 month calving interval. These goals can be met by effective grazing supplementation or economical, balanced drylot diets. Research demonstrates that maternal nutrition during gestation affects not only cow performance, but potentially has lasting effects on subsequent progeny; a concept known as fetal programming. Thus, management of breeding females should account for effects on growth and body composition of the future calf crop. Generally, both extreme maternal nutrient restriction and overfeeding result in increased adiposity, decreased muscle development, and greater insulin resistance of progeny; with variable results on postnatal growth. Research demonstrates that enhanced maternal nutrition during gestation may impart desirable effects on the growth and carcass characteristics of subsequent progeny; however, results are conflicted and underlying mechanisms are not completely understood.

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