# BEEF SPECIES SYMPOSIUM:
# An assessment of the 1996 Beef NRC: Metabolizable protein supply and demand and effectiveness of model performance prediction of beef females within extensive grazing systems[1,2,3]

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**ABSTRACT:** Interannual variation of forage quantity and quality driven by precipitation events influence beef livestock production systems within the Southern and Northern Plains and Pacific West, which combined represent 60% (approximately 17.5 million) of the total beef cows in the United States. The beef cattle requirements published by the NRC are an important tool and excellent resource for both professionals and producers to use when implementing feeding practices and nutritional programs within the various production systems. The objectives of this paper include evaluation of the 1996 Beef NRC model in terms of effectiveness in predicting extensive range beef cow performance within arid and semiarid environments using available data sets, identifying model inefficiencies that could be refined to improve the precision of predicting protein supply and demand for range beef cows, and last, providing recommendations for future areas of research. An important addition to the current Beef NRC model would be to allow users to provide region-specific forage characteristics and the ability to describe supplement composition, amount, and delivery frequency. Beef NRC models would then need to be modified to account for the N recycling that occurs throughout a supplementation interval and the impact that this would have on microbial efficiency and microbial protein supply. The Beef NRC should also consider the role of ruminal and postruminal supply and demand of specific limiting AA. Additional considerations should include the partitioning effects of nitrogenous compounds under different physiological production stages (e.g., lactation, pregnancy, and periods of BW loss). The intent of information provided is to aid revision of the Beef NRC by providing supporting material for changes and identifying gaps in existing scientific literature where future research is needed to enhance the predictive precision and application of the Beef NRC models.

**Key words:** amino acid, ammonia, cow, grazing, rumen



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## INTRODUCTION

Nutritional composition of rangeland forages in arid and semiarid regions is highly variable both within and among years, with nutrient quality and quantity often limiting livestock performance. The 1996 Beef NRC provides nutritionists, managers, and producers with a model to predict animal performance and implement management strategies to accomplish production goals. Within the context of beef cow-calf production systems, the 1996 Beef NRC model functions well in situations where physiology or environmental demands are minimal or controlled (i.e., static) but is less accurate when physiology or environmental demands are elevated or inconsistent (i.e., dynamic). Therefore, the intent of the present work is to evaluate the 1996 Beef NRC in both static and dynamic production environments in regard to MP supply and demand. Our objectives are 1) to identify areas within the 1996 Beef NRC that could be refined so that future Beef NRC models would have greater precision in predicting protein supply and demand for beef cattle production within extensive grazing systems and 2) to document both strengths and weaknesses of the model in terms of predicting extensive range beef cow performance within arid and semiarid environments in the western United States. Therefore, this review elaborates a need to develop a more robust model for predicting beef cow performance within specific environments to which cows are conditioned. Accomplishment of this goal should lead to improved animal production by informing livestock producers and land managers when strategic, least cost supplements or feeding protocols are needed to achieve economic and environmental production goals. It is anticipated that this effort will compliment previous reviews of the 1996 Beef NRC (Lardy et al., 2004; Patterson et al., 2006) and provide useful information for the NRC Subcommittee on Nutrient Requirements for Beef Cattle.

## ROLE OF ARID AND SEMIARID RANGELANDS IN ANIMAL PRODUCTION SYSTEMS

### *Environment*

Ecological succession of native rangelands has been shaped by the plant-animal interface. Domestic livestock species have been essential components of agriculture and human food systems for thousands of years (Bradford, 1999). Nonarable lands are the majority of land types on the Earth's surface. Holechek et al. (1989) estimated that approximately 11% of the Earth's land area is cultivated, 24% is in permanent pasture, 31% is forest or woodland, and the remaining 34% is composed of glaciated areas, mountain ranges, and urbanized or industrialized land. The Food and Agriculture Organization (2000) projected that approximately 75% of the Earth's land surface has soil constraints that limit or restrict arable use. Sustainable use of these lands to produce food and fiber for a growing world population necessitates the inclusion of suitable grazing practices with ruminant livestock (Lardy and Caton, 2012). The world population is expected to reach over 9 billion by 2050 (United Nations, 2008; mean variant), and the majority of population growth is expected in developing countries where there are currently increasing demands for animal-based food products (Council for Agricultural Science and Technology, 1999). Much of the nonarable land in the world consists of native rangelands or forested areas in arid and semiarid environments. These environments are well suited for ruminant livestock and are typical of extensive western U.S. beef production systems.

Beef livestock production in arid and semiarid environments within the Southern and Northern Plains and Pacific West combined represents 60% (approximately 17.5 million) of the total beef cows in the United States (USDA-NASS, 2013). Efficient use of rangelands and pastures for livestock grazing is becoming increasingly more important as urban development and population growth continue to escalate. These and other factors increase pressure on rangeland managers, livestock producers, range livestock nutritionists, and industry professionals to optimize the use of rangelands while preserving this resource for future generations. Increasing costs of production also elevate the need for the implementation of practices that ensure sustainability of the range livestock industry to continually provide a supply of high-quality protein for human consumption. An abundance of diverse management systems exist within these arid and semiarid regions related to grazing and supplementation strategies that are designed to overcome climatic, environmental, and economic hurdles while concomitantly improving sustainable range beef cattle production.

Native forages exhibit wide variations in nutrient quality and quantity (Patterson et al., 2006; Lardy and Caton, 2012). Consequently, a need for supplementation is often required to offset nutrient deficiencies and improve or sustain production during periods when forage quantity or quality becomes inadequate to meet animal requirements. Interannual variation in timing and amount of precipitation accompanied by corresponding ambient temperatures drives annual primary forage production (Sims and Singh, 1978a,b; Grings et al., 2005; Waterman et al., 2007a). This relationship holds firm for both warm-season (Forbes, 1999) and cool-season (Küchler, 1964) grass-dominated regions. For example, Heitschmidt and Vermeire (2005) identified that 70% of the aboveground net annual primary production (**NAPP**) was achieved by June 1 and that by July 1 the percentage reached 90% in the Northern Great Plains. Inclusion of region- or precipitation-zone-specific data along with forage nutrient compositional change (in relation to both increasing and decreasing forage nutrient quality) will help model animal performance predictions as well as identify limiting nutrients that impact animal performance. Across the Southern to Northern Plains and into the Pacific West, NAPP, precipitation, and forage types differ greatly in how $CO_2$ is fixed in the photosynthetic pathway and the subsequent end products of 3 or 4 carbon compounds. These environmental factors are significant because they shape nutrient supply curves for beef cattle in a regionally specific manner, making it almost impossible for a single nutritional model to accurately predict cow performance unless geographically specific nutrient supply data are known.

### *Need for Accurate Prediction Models*

Nutritionists rely on experimental results that drive prediction models to create supplements that meet specific production goals for range livestock in various physiological states. Although substantial information exists for supplementation protocols for energy, protein, and other nutrients, the primary focus of the present review will be on protein. There are 2 primary sources of protein a ruminant will consume. The first is degradable intake protein (**DIP**), which includes nonprotein N (**NPN**; e.g., urea, biuret, and ammonia, which are predominately highly soluble N sources for ruminal microorganisms) and true degradable intake protein (the portion of dietary feed protein degraded in the rumen for ruminal microorganisms). The second is undegradable intake protein (**UIP**; the portion of dietary feed protein not readily available for ruminal microorganism degradation that also includes rumen-protected AA). Both primary sources of dietary protein contribute to the MP supply delivered to the host animal, as will be discussed in subsequent paragraphs. Nutrient partitioning can be influenced by the type of protein supplied (Hunter and Magner, 1988; Miner and Petersen, 1989; Miner et al., 1990), the use of rumen-protected AA (Richardson and Hatfield, 1978; Waterman et al., 2007b, 2012), or a supplement that supplies specific nutrients that target both an energy and protein deficiency in the host animal (Waterman et al., 2006; Mulliniks et al., 2011, 2013).

### *Perspective on the Transition from CP to MP Supply and Demand Systems*

Protein requirements for beef cattle have been traditionally listed in terms of CP (NRC, 1984, and earlier versions). Modeling of protein requirements on CP basis was effective because it was easily determined in the laboratory and it fairly approximated dietary protein targets for beef cattle in many situations, being more effective in mature animals and less effective in rapidly growing or high-producing cattle as microbial protein was inadequate to meet their needs. Inefficiencies of the factorial CP system outlined in the 1984 Beef NRC were recognized by that and previous NRC subcommittees when addressing protein requirements for beef cattle; however, adequate data were not present to move past CP-based systems. The primary drawbacks for the CP system included the lack of accounting for ruminal (i.e., microbial) and postruminal (i.e., intestinal or host animal) demands. Research in the areas of ruminal N needs (Burroughs et al., 1974; Satter and Slyter, 1974; Clanton, 1978; Orskov and McDonald, 1979; Broderick and Kang, 1980; Broderick et al., 1988) and postruminal (Orskov et al., 1979; Prior et al., 1981; Orskov, 1982) supply and demand was very active while factorial CP systems were being used to describe beef cattle protein requirements. Following these efforts, there has been a period lacking adequate data and methodologies, which has prevented moving forward toward a more descriptive protein system for beef cattle.

In 1985, the NRC Subcommittee on Ruminant Nitrogen Usage (NRC, 1985), building on concepts outlined by Annison and Lewis (1959) and data generated in the ensuing 25 yr, made a major step forward by outlining and recommending a protein system for ruminants that recognized both ruminal (microbial) and host animal needs. They suggested that host animal physiological demands were for absorbed true protein and that existing data and modeling techniques were emerging to the point that advancement past a factorial CP system was possible and likely desirable from a host animal and production system efficiency standpoint. Adaption of an absorbable protein or MP system for ruminants has been implemented in various forms (INRA, 1989; NRC, 1989, 1996, 2000, 2001, 2007; Agricultural and Food Research Council, 1993; Commonwealth Scientific and Industrial Research Organisation, 2007). Although there are notable differences in applications, the underlying principles and concepts are essentially the same and represent significant movement away from a CP system and into a MP system for ruminants in general and beef cattle specifically.

Movement from a CP to an MP system for ruminants presents advantages (NRC, 1985). In terms of beef cattle, the Beef NRC (NRC, 1996) indicated that there were 2 motives for moving to the MP system instead of CP: more data had become available about the 2 factors used in the MP system (i.e., ruminal and postruminal supply and demand), and the CP system is based on the flawed assumption that CP in all feedstuffs is created equal, having conversion efficiencies similar to MP (NRC, 1996). The movement to an MP-based system is understandable from both a theoretical and practical view point. Theoretically, a well-developed MP system would more accurately meet the demands for both microbial protein synthesis and for host animal AA demand. From a practical view point, both the swine and poultry industries realized significant increases in efficiencies of feed utilization with transitions from CP to more ideal protein-based systems. In addition, increasing synchrony between protein supply and demand should, at least theoretically, result in reduced environmental nutrient load.

Progression from a CP to a MP system can be viewed as a step toward balancing for AA needed to optimize physiological needs and a growth-based system. However, ruminant animals present unique challenges that are not present in other species. The concept and relevance of specific AA supplementation as rumen-protected products have been discussed for decades (Chalupa, 1975; Clark, 1975). Progress with rumen protection technologies has led to protected methionine and lysine in markets, has considerable traction in the dairy industry (Sniffen et al., 2013a,b), and has become an active area of research for beef cattle and sheep (Hess et al., 1998; Klemesrud et al., 2000; Archibeque et al., 2002; Waterman et al., 2007b, 2012; Meyer et al., 2011; Peine et al., 2013). The role of rumen-protected AA will be discussed in more detail in subsequent sections.

Nutritionists have questioned the adequacy of the MP system (NRC, 1996) for predicting protein supply and demand of beef cows grazing arid and semiarid rangelands. A better understanding of nutrient supply and demand of beef cows grazing arid and semiarid rangelands would improve predictive models, which could aid in designing least cost supplements that compliment rangeland forage nutrient composition (McCollum and Horn, 1990; Caton and Dhuyvetter, 1996). Lardy et al. (2004) developed computer-based beef cow nutrition programs using the 1996 Beef NRC. They conclude that to increase the use and effectiveness of the 1996 Beef NRC model for grazing beef cows, several model inputs are needed: 1) cost-effective commercial laboratory procedures to estimate DIP, 2) reliable estimates of microbial efficiency for digestion of forages of various qualities that occur across season, 3) improved estimates of dietary TDN associated with forage diets, 4) improved estimates of DIP and MP requirements of cattle grazing forages, and 5) incorporation of reliable estimate of N recycling into estimates of supply and demand. Also, fundamental assessments of DMI and nutrient composition of consumed forages remain a difficult challenge in arid and semiarid beef cattle grazing environments (DelCurto and Olson, 2010; Dove, 2010) and further complicate implementation of MP systems in extensive grazing settings.

Recently, DelCurto and Olson (2010; p. 4) concluded that "for many range livestock nutritionist, the 1996 Beef NRC has limited application to applied cow-calf nutrition." They also concluded that "balancing protein in terms of MP, rumen undegradable protein (UIP), and rumen degradable protein (DIP) is beyond the needs of the average range livestock manager." Rationales provided for these conclusions were analogous to research needs articulated by Lardy et al. (2004) and proposed that implementation of supplementation strategies that optimized the use of low-quality forage and that were designed for reduced labor inputs lacks relevant data for inclusion as model components from cattle grazing arid and semiarid rangelands. Another conspicuous deficit of the model is the inaccuracies of the 1996 Beef NRC model to predict forage intake responses to protein supplementation. It can also be inferred from the work of Lardy et al. (2004) and DelCurto and Olson (2010) that the 1996 Beef NRC model does not appear to account for the changes in nutrient requirements occurring during undernutrition and BW loss assumed to be manifested in the field as adaptability. Physiologically, the mature beef cow can be triggered to better capitalize on recycled N and/or AA conservation to either meet the needs or reduce the demands during times of limited nutrient supply. Data on the effectiveness of frequency of supplementation strategies for cows (Houston et al., 1999; Bohnert et al., 2002; Farmer et al., 2004a) but not heifers (Moriel et al., 2012) and on the ability of cows to adapt to environments in terms of energy use conservation (Keren and Olson, 2006a,b) also support the concept that the current 1996 Beef NRC does not adequately account for plasticity and adaptability of the mature beef cow in arid and semiarid range conditions. An improvement in the next Beef NRC would be a model that does not ignore the contribution of MP for energy needs rather than going toward lean tissue growth. Furthermore, the ability of ruminants to utilize N recycled back to the rumen, which supports microbial protein synthesis, especially when supplements are fed on a prorated basis (i.e., daily dose delivered 2 or 3 times/wk), will be an important addition to the future Beef NRC models.

## PROTEIN SUPPLY AND DEMAND

### *Degradable and Undegradable Intake Protein*

Degradable intake protein, also known as rumen degradable protein (**RDP**), is the fractional portion of protein that is degraded in the rumen of livestock and is the primary source of N (or AA and peptides) for ruminal microorganisms. For the purpose of continuity with the acronym used in the current Beef NRC (NRC, 1996, 2000), DIP will be used to define this fraction (i.e., portion of dietary feed protein readily available for ruminal microorganism degradation). The ability of ruminal microorganisms to use NPN compounds as an N source for cell growth and consequently provide true protein to host tissues via intestinal digestion of microbial cells has been known for a long time (Owens et al., 1943; Briggs et al., 1947; Annison and Lewis, 1959). Since the initial understanding that ruminal microorganisms could degrade and use dietary protein or NPN sources for growth, the quantification of minimal and maximal ruminal ammonia supply and demand relationships to establish efficient ruminant feeding systems has been an area of active research because of the potential for greater understanding leading to higher N use efficiencies. Optimizing use of DIP and/or NPN as substrates for ruminal bacteria protein synthesis has and will continue to be of practical importance. Reasons for this include the following: 1) supplying dietary DIP is less expensive compared with UIP, 2) true protein can be well suited for more strategic applications during periods of high demand, and 3) potential increased efficiencies of whole-system N economies and concomitant reductions in environmental N burdens may be realized through optimizing the source of dietary N supply.

Various approaches have been used to quantify DIP, including solubility approaches (Wohlt et al., 1973; Waldo and Goering, 1979), enzymatic degradation (Krishnamoorthy et al., 1983), and in situ techniques using nylon or Dacron bags placed into the rumen (Orskov and McDonald, 1979; Nocek, 1985; Caton et al., 1988a; Mathis et al., 1999b). Most of these approaches also allow for calculating UIP, which is also known as rumen undegradable protein.

Rangelands in the United States, along with other arid and semiarid areas worldwide, often consist of dormant low-quality forages that are deficient in protein because of drought or senescence (McCollum et al., 1985; Krysl et al., 1987). Generally, insufficient DIP is considered the first limiting nutrient when range livestock graze low-quality forages (Köster et al., 1996; Johnson et al., 1998; Sletmoen-Olson et al., 2000b). Hollingsworth-Jenkins et al. (1996) estimated the supplemental DIP needs of 4-yr-old gestating beef cows grazing winter Sandhills range in Nebraska to be 62 to 140 g/d to meet daily requirements of 340 to 430 g/d, or 7.1% of consumed digestible OM, with the balance of DIP coming from forage and recycled N. This is in agreement with Johnson et al. (1998), who concluded that cattle grazing mixed grass prairie of western North Dakota were between 90 and 250 g deficient in DIP during November and December. More recent work (Cline et al., 2009, 2010) from western North Dakota concluded that N and, specifically, DIP deficiencies could occur in grazing animals after September with the onset of fall dormancy, independent of grazing management strategies.

Microbial protein synthesis (**MPS**) in the rumen can provide 40% to nearly 100% of the true protein flowing to the small intestine (NRC, 2000, 2007). Bacteria use rumen degradable true protein, dietary NPN, and recycled N to meet the demand for MPS. Microbial efficiency of protein synthesis (**MOEF**) was set by the Beef NRC (NRC, 1996, 2000) at 13% of TDN, with recognition that MOEF varies depending on numerous factors. Beef NRC (NRC, 1996) equations allow for flexible adjustments of MOEF, depending on dietary conditions. At the time of construction, existing data regarding MOEF were from pen-fed situations using steers in controlled environments. Although these data were the best available at the time, they do not reflect the unique environmental and physiological characteristic associated with grazing arid and semiarid rangelands or account for adaption in metabolic efficiency or grazing behavior. For example, Krysl et al. (1987) demonstrated wide variation in diet selectivity as season advances. Therefore, additional understanding of MOEF in grazing beef cattle is needed to enhance the NRC model.

Supplementing DIP in the form of true protein to beef cattle consuming low-quality forages (i.e., low protein, high NDF) has been associated with increased intake and digestion (McCollum et al., 1985; Caton et al., 1988a,b; Sletmoen-Olson et al., 2000b; Bandyk et al., 2001; Reed et al., 2007) and maintenance of prepartum body condition and/or BW (Clanton and Zimmerman, 1970; Mathis et al., 1999a). Since NPN is a less expensive approach to providing DIP than natural protein, maximizing proportions of NPN included in beef cattle supplements without compromising performance is desirable. Köster et al. (2002) indicated that inclusion of urea in supplements at less than 45% of DIP would not significantly depress performance of prepartum cows grazing dormant tall grass prairie in Kansas. Others (Beaty et al., 1994; Farmer et al., 2001) observed that infrequent (i.e., 2 to 3 times/wk vs. daily) DIP supplementation can be practiced without greatly affecting performance outcomes of winter grazing beef cows. Farmer et al. (2004b) found that inclusion of NPN (30% or less of DIP concentrations) in protein supplements fed on alternative days to beef cows grazing dormant tallgrass prairie did not compromise beef cow performance. However, as NPN proportions of DIP increased above 15% when CP was >30%, the frequency of feeding needed to be increased daily to realize the full effects of supplemental protein (Farmer et al., 2004b).

The effectiveness for alternative frequencies of protein supplementation to beef cattle consuming low-quality forage (Houston et al., 1999; Bohnert et al., 2002; Currier et al., 2004a,b,c; Farmer et al., 2004a,b; Schauer et al., 2005) indirectly implicated N recycling as an important process of N conservation in extensive grazing systems. Indeed, Wickersham et al. (2008) concluded that in cattle consuming low-protein forage-based diets, N recycling played a significant role in the effectiveness of the alternative frequency of supplementation strategies. More recent work (Huntington et al., 2009) found that beef steers consuming high-forage diets can recycle 80% or more of urea produced. This indicates the importance of N recycling in cattle consuming low-protein, high-forage diets. Nitrogen recycling data from beef cows existing for extended periods (thereby allowing adaptation) on lower-quality forages are needed.

Although ruminal N and carbohydrate synchrony is sound in theory, it has been difficult to document in practice (Barton et al., 1992; Hall and Huntington, 2008; Reynolds and Kristensen, 2008). The evaluation of protein supplementation frequency data discussed in the aforementioned paragraph provides evidence that there is little to no benefit of synchrony of dietary N release and carbohydrate fermentation in the rumen. This is particularly the case for beef cattle consuming low-protein forages typical of those existing during much of the dormant season in arid and semiarid rangelands throughout the world. Sufficient data may not yet be available to appropriately adjust protein supply and demand estimates for either recycling or asynchronous supply through infrequent supplementation. This is more likely the case with grazing beef cattle than those housed and fed in pens.

Supplemental dietary protein (true protein or NPN) is needed for proper growth of ruminal microorganisms and concomitant supply of MP to the lower tract. Microbial N flowing to the intestine is calculated to be 80% true protein, which is in turn assumed to be 80% absorbable (NRC 1996, 2000). Forty percent to nearly 100% of absorbed AA can be supplied to ruminants via microbial protein, with practical ranges being from 50% to 75% (NRC 2000). As discussed above, protein can be classified as either DIP or UIP. In addition to research on supplementing with DIP to overcome inadequacies in protein supply discussed in the preceding paragraphs, UIP can also be used to overcome protein deficiencies and/or supply limiting AA. Unfortunately, the relative DIP and MP requirements for grazing cattle are unreliable using the current Beef NRC (Lardy et al., 2004), and direct in vivo measures of DIP and UIP from grazing cattle in general and cows specifically are sparse in the literature.

Existing data from studies on UIP supplementation in forage-fed cows or steers, particularly those studies where DIP has been considered adequate, derived from natural protein sources, and when animals were considered in positive energy balance demonstrate little effect from supplemental UIP (Reilly and Ford, 1971; Blasi et al., 1991; Alderton et al., 2000; Sletmoen-Olson et al., 2000a; Sletmoen-Olson et al., 2000b). In contrast, Miner et al. (1990) reported positive responses in beef cows provided UIP supplements and grazing winter rangelands in Montana. However, their responses could also be explained by slightly inadequate levels of dietary DIP, which would provide an opportunity for recycled UIP supplemental N to boost microbial responses in the rumen. It is also possible that positive responses were manifested by specific AA contained in the UIP supplements. Furthermore, it may be more prudent to accurately assess the adequacy of DIP by using blood urea N as an indicator of dietary protein status. Using blood urea N concentrations of 8 to 12 mg/100 mL as an indicator of proper protein balance, >12 mg/100 mL represents an excess of dietary protein, and <8 mg/100 mL indicates a deficiency in dietary protein, regardless of ruminal ammonia concentrations. Recently, Wickersham et al. (2009) reported that recycled N from UIP supplements is incorporated into ruminal microbial cells, providing evidence that the responses observed in the Miner et al. (1990) study were partially, if not completely, the result of recycling. These conclusions are corroborated by the increased in situ rate of forage NDF and CP disappearance data reported in response to high UIP supplementation reported by Reed et al. (2007).

Although limited, research investigating the effects of UIP supplements on endocrine responses indicates UIP supplements may alter metabolic (Sletmoen-Olson et al., 2000b; Kane et al., 2004; Reed et al., 2007) and reproductive (Strauch et al., 2001; Kane et al., 2004) endocrine patterns. Interestingly, Sletmoen-Olson et al. (2000a) reported that calf birth weights were greater for cows fed moderate levels of UIP compared with those fed low or high amounts of UIP. In their studies (Sletmoen-Olson et al., 2000a,b) adequate DIP from natural protein sources (i.e., casein) and increased amounts of UIP using corn gluten meal and blood meal were provided. Reported changes in birth weights in response to moderate, but not low or high, amounts of MP supplied by UIP may be indicative of developmental programming (i.e., in utero nutrient environments impact offspring performance) by gestational MP supply. Others (Stalker et al., 2006; Martin et al., 2007; Larson et al., 2009) have also reported developmental programming by protein supplementation during gestation. This area of developmental programming in response to MP supply coupled with potential metabolic effects of rumen-protected AA warrants further investigation.

### *Specific Amino Acids*

Ruminants grazing arid and semiarid rangelands often require supplementation to meet nutritional requirements. However, supplementation may not provide the proper balance of AA delivered to the small intestine for absorption, indicating a need for postruminal supply of limiting AA to optimize utilization of N absorbed by the ruminant. Postruminal delivery of dietary UIP and microbial protein (MP supply) may not eliminate a specific AA deficiency if the UIP portion is deficient in the first limiting AA. Therefore, inclusion of rumen-protected AA may improve efficiency of N usage for fetal development and maternal metabolism in beef cows grazing dormant forages.

Amino acid requirements for lactating dairy cows have been well studied, but limited research exists on the evaluation of specific individual AA for beef cow production in extensive grazing systems. A review by Titgemeyer and Löest (2001) concluded that severe deficiencies of specific AA are unlikely under most cattle grazing conditions because both the demand and supply of metabolizable AA are proportional to energy supply. Both MP requirements and MP supply from microbial protein synthesis (provided rumen available N is adequate) are energy-dependent processes (NRC, 1996). This relationship between energy and protein is particularly true for growing animals. Nevertheless, Archibeque et al. (2002) demonstrated that metabolizable methionine was limiting for steers consuming tall fescue, and Gomez et al. (2011) reported that rumen-protected methionine supported growth of heifers grazing kikuyu pasture along with supplemental urea and blood meal.

Environmental stressors during gestation and/or lactation, along with forage quality and quantity, may encourage a cow to mobilize body reserves to increase energy supply to support its present physiological state. During these physiological states, the relationship between energy and protein is altered, and demand for specific AA could exceed the metabolizable AA supply. Hess et al. (1998) demonstrated that rumen-protected methionine and lysine supplementation during late gestation and early lactation increased milk production in primiparous beef cows consuming annual rye hay. Waterman et al. (2007b) also demonstrated that postruminal supply of methionine was limiting, as more N was retained with methionine infused into the abomasum, in late gestating beef cows consuming low-quality forages with supplemental urea to supply adequate DIP.

There is emerging evidence that specific AA are required for embryonic development. Adequate essential AA present in the uterus will improve blastocyst activation and trophoblast motility (Groebner et al., 2011; Bazer et al., 2012a,b; González et al., 2012). Concentrations of arginine in uterine flushings was greater on d 18 in pregnant vs. nonpregnant heifers (Groebner et al., 2011). Arginine via nitric oxide stimulates mammalian target of rapamycin cell signaling, which can stimulate fetal production of the pregnancy recognition signal, interferon-tau (Bazer et al., 2012b). In addition, proliferation, migration, and mRNA translation by ovine trophectoderm cells were stimulated with the inclusion of arginine (Bazer et al., 2012a). Arginine is needed for polyamine synthesis. Polyamines are rapidly synthesized in the placenta and endometrium during early (i.e., d 40 to 60) and late pregnancy (i.e., d 100 to 140) in sheep (Kwon et al., 2003). Polyamines participate in many metabolic pathways, which include the regulation of angiogenesis and embryonic development. Arginine supplementation has improved embryonic survival during early pregnancy in naturally mated ewes (Luther et al., 2008). Recently, Peine et al. (2013) reported that neonatal growth in lambs could be enhanced with maternal rumen-protected arginine supplementation. While these data are intriguing, considerable research efforts are needed to establish effectiveness and applicability of rumen-protected arginine specifically and other AA in general on embryonic survival in beef cattle managed within extensive western range conditions.

In this section on protein supply and demand, we have discussed both types of protein used by ruminants (i.e., DIP and UIP) and have pointed out areas in which the current NRC is less than accurate, such as the microbial efficiency of protein synthesis, the ability to account for N recycling, and the ability to establish and balance diets based on their AA composition. Advancement in these areas will greatly enhance future versions of the Beef NRC.

## CURRENT BEEF NRC: PREDICTIONS VS. ACTUAL OUTCOMES

### *Relevant Example Data Sets*

Two data sets on BW of cows at different times throughout numerous production years at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory (**LARRL**) near Miles City, MT, were used to evaluate the 1996 Beef NRC predictions in BW change based on estimates of forage quality obtained from 15 yr of ruminal extrusa samples collected at LARRL. One data set was from the Line 1 Hereford herd that has been closed to outside genetics since 1934. Data from 2003 to 2012 were summarized and evaluated with the 1996 Beef NRC (Table 1). The second data set was from the Composite Gene Combination (CGC) herd established in 1979 (also closed to outside genetics). This composite is made up of 1/2 Red Angus, 1/4 Charolais, and 1/4 Tarentaise. Data from 2002 to 2010 were summarized for this herd and were evaluated with the 1996 Beef NRC (Table 1).

### *Methods and Approach for Comparative Analyses*

Inputs used in the 1996 Beef NRC model to predict performance based on the aforementioned data sets followed guidelines described by Lardy et al. (2004). Level 1 of the 1996 Beef NRC was selected, and breed type(s), cow age, and production stage were entered in the animal section. In the management section, the pasture feature was disabled, and MOEF was modeled at both the default 13% and at 8% (only during the weaning to precalving period). Parameters in the environment section of the model were left at default settings, and feed estimates from the 15 yr of ruminal extrusa samples were entered into the feed library for the quality of native range for late fall through winter as 6.7% CP, 50.5% TDN, 67.5% NDF.

The BW data sets from LARRL were compiled by herd and analyzed statistically using SAS (SAS Inst. Inc., Cary, NC). Both the Line 1 Hereford and CGC herds are spring calving herds that calve in late February

**Table 1.** Mean BW (kg) of Line 1 Herefords at weaning and precalving and Composite Gene Combination (CGC) cows at initiation of winter supplement, where treatments are adequately supplemented cows receiving an equivalent of 1.81 kg/d and marginally supplemented cows receiving an equivalent of 1.09 kg/d of a 24% CP alfalfa hay while grazing dormant winter range (6.7% CP, 50.5% TDN, 67.5% NDF), and precalving for 3- and 7-yr-old cows at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory used to evaluate the 1996 Beef NRC

| | | | | | CGC cows | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Line 1 Hereford cows | | | | Adequately supplemented cows | | | | Marginally supplemented cows | | | |
| | Weaning | | Precalving | | Initiation of winter TRT | | Precalving | | Initiation of winter TRT | | Precalving | |
| Item | 3 yr | 7 yr | 3 yr | 7 yr | 3 yr | 7 yr | 3 yr | 7 yr | 3 yr | 7 yr | 3 yr | 7 yr |
| *n* | 305 | 105 | 305 | 105 | 279 | 107 | 107 | 153 | 257 | 135 | 257 | 135 |
| Year | | | | | | | | | | | | |
| 2002 | — | — | — | — | 531 | 593 | 567 | 640 | 547 | 624 | 553 | 616 |
| 2003 | 512 | 612 | 578 | 632 | 510 | 562 | 549 | 601 | 508 | 586 | 577 | 622 |
| 2003 | 494 | 586 | 532 | 608 | 526 | 612 | 532 | 612 | 535 | 587 | 534 | 604 |
| 2005 | 515 | 589 | 545 | 624 | 482 | 572 | 559 | 652 | 460 | 568 | 561 | 616 |
| 2006 | 481 | 542 | 530 | 619 | 492 | 539 | 531 | 602 | 504 | 575 | 504 | 599 |
| 2007 | 518 | 620 | 556 | 611 | 461 | 567 | 526 | 548 | 522 | 565 | 522 | 584 |
| 2008 | 532 | 585 | 549 | 624 | 467 | 584 | 494 | 599 | 479 | 583 | 478 | 585 |
| 2009 | 550 | 619 | 559 | 587 | 475 | 563 | 485 | 592 | 467 | 552 | 467 | 586 |
| 2010 | 548 | 651 | 582 | 670 | 439 | 548 | 469 | 551 | 479 | 538 | 479 | 537 |
| 2011 | 567 | 623 | 542 | 484 | — | — | — | — | — | — | — | — |
| 2012 | 459 | 562 | 587 | 623 | — | — | — | — | — | — | — | — |

through early March; breeding begins in late May (typically a 60-d breeding season), and calves are weaned in late October or early November. Line 1 Hereford cow BW and ADG data were summarized by year (2003 to 2012), and least squares means were generated for BW at weaning and precalving by age of cow for each year. Data were graphically evaluated by age classification, and 2 age classes were identified for further analysis. The first age group represented 3-yr-old cows, which are often considered the most vulnerable age of cows to stay in herd. The second age group identified was 7-yr-old cows, which represent the most stable cows, or those that have the greatest mean BW at weaning in the fall (indicating mature BW has been achieved). Least squares means (actual) for ADG for both 3- and 7-yr-old cows were generated from weaning to precalving (≈ 139 d). Linear regression and ANOVA were preformed testing actual vs. predicted ADG using the 1996 Beef NRC and the PROC REG and PROC MIXED of SAS.

Body weight and ADG data for the CGC cow herd were also analyzed by year (2002 to 2010), and BW and ADG least squares means were generated for age and treatment (cows assigned to a lifetime treatment of 1 of 2 levels of winter supplement). A more detailed description of treatment structure is discussed by Waterman et al. (2011). Least squares means were generated for BW at initiation of winter feed and precalving for treatments and age of cow for each year. Data were graphically evaluated as previously mentioned, and the same 2 age classes were identified for further analysis. Mean ADG from initiation of winter feed (beginning approximately the first week of December) to precalving (≈ 139 d) were calculated for both 3- and 7-yr-old cows. Linear regression and ANOVA were preformed testing actual vs. predicted ADG using the 1996 Beef NRC and the PROC REG and PROC MIXED of SAS.

### *Current Beef NRC Predictions and the Existing Data*

Using the 1996 Beef NRC model, replacement heifers developed on native Great Plains rangelands from LARRL (R. C. Waterman, unpublished data) and results published by Mulliniks et al. (2013) were evaluated (actual vs. predicted by NRC), and both data sets were in close agreement with predictions provided by the 1996 Beef NRC. One observation regarding heifers being developed on native range in late winter to early spring was that the current Beef NRC model does not accurately adjust for compensatory gain, and consequently, the accuracy of the model prediction was poor. The 1996 Beef NRC model predicted ADG to be 0.52 kg/d for ME-allowed ADG and 0.54 kg/d for MP-allowed ADG, whereas the actual ADG was 1.19 kg/d. These data indicate an opportunity for the next generation of Beef NRC models to incorporate region-specific data that match forage quality and quantity to stage of production within the constraints of environmental conditions of specific regions at any point in time in a calendar year. In other words, regions need to be identified in relation to forage type (i.e., $C_3$ or $C_4$ forages), net annual primary forage production, and how forage conditions may rapidly improve or decline depending on season and other environmental constraints. These change

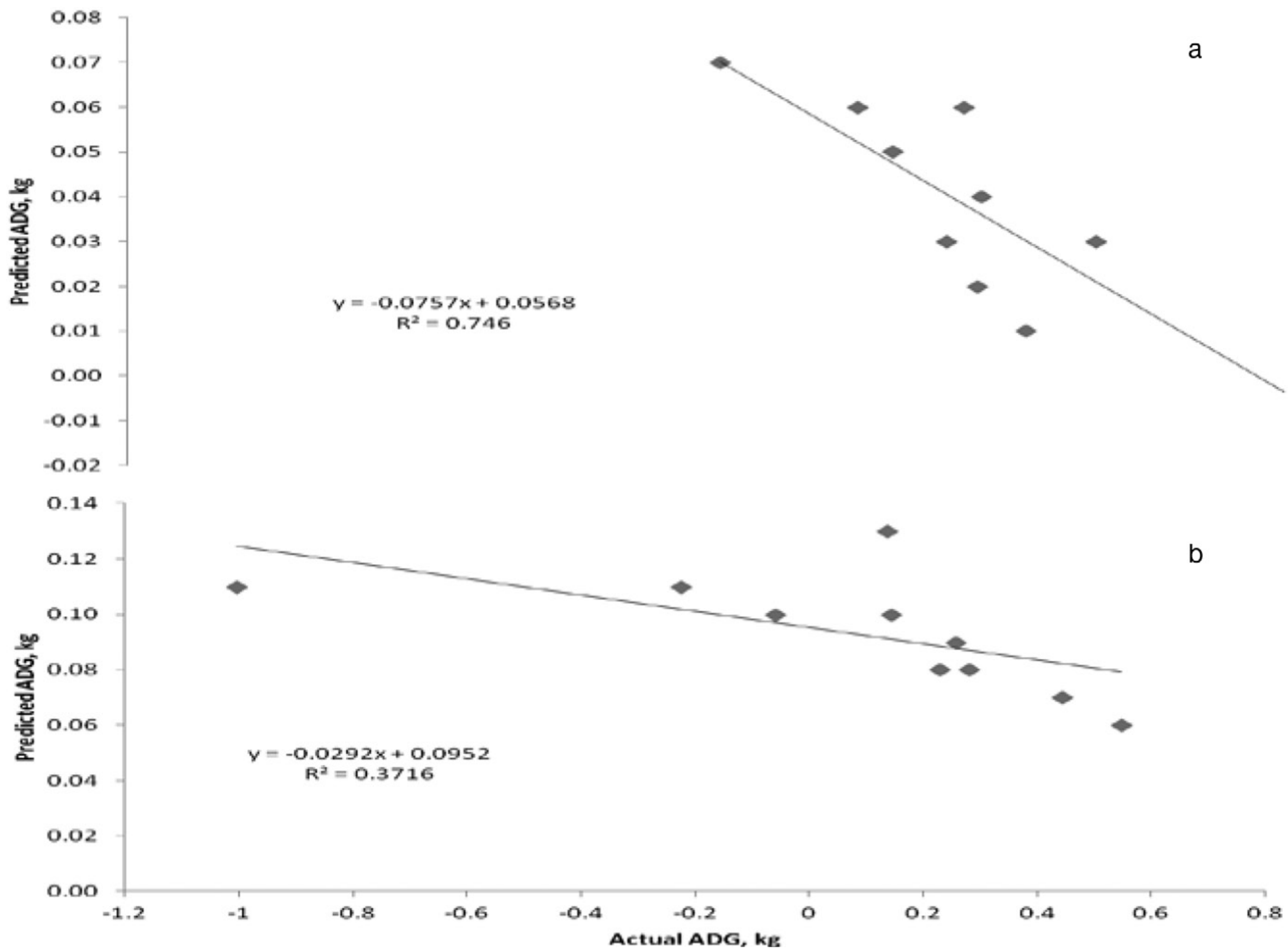


**Figure 1.** Regression of mean ADG from weaning to precalving (≈ 139 d) predicted by the 1996 Beef NRC model on actual ADG for (a) 3-yr-old and (b) 7-yr-old Line 1 Hereford cows over a 10-yr period at Fort Keogh Livestock and Range Research Laboratory near Miles City, MT. Cows received 1.6 kg/d of a 24% CP alfalfa hay while grazing dormant winter range (6.7% CP, 50.5% TDN, and 67.5% NDF).

dramatically in western U.S. rangeland production settings as you move from north to south and east to west.

Regression analysis for 1996 Beef NRC predictions for ADG from weaning to precalving (≈ 139 d) on actual ADG for Line 1 Herefords at LARRL is presented in Fig. 1. For 3-yr-old cows, there was a favorable agreement ($r^2 = 0.75$), and there was a smaller agreement with mature (7-yr-old) cows that have reached their mature BW ($r^2 = 0.37$). However, when actual and predicted ADG were compared for each age group, the 1996 Beef NRC underpredicted performance for the 3-yr-old cows ($P < 0.01$) and accurately predicted performance for mature 7-yr-old cows ($P = 0.81$; Table 2). In the case of the 3-yr-old cows, this may indicate that the slope of the regression line is reasonable but maintenance requirements are less than predicted by the 1996 Beef NRC model. In addition, it is important to point out that by changing the model parameters to adjust for MOEF, both DIP and MP balances change but do not affect the prediction of animal performance. In other words, changing MOEF between 8% and 13% adjusts both DIP and MP prediction, but changes in DIP and MP do not feed back into the performance portion of the model; therefore, days to gain or lose a BCS do not change. It would seem reasonable to assume that changes in DIP and MP supply should impact ADG at some degree and should be evaluated and considered in future model development. Additionally, predictions for DIP and MP seem reasonable (although they currently cannot be truly evaluated) and should remain in the next installment of the Beef NRC.

Regression analysis for 1996 Beef NRC predictions for ADG from initiation of winter feed to precalving (≈ 97 d) for CGC cows at LARRL are presented in Fig. 2. In the case of young (3-yr-old) and mature (7-yr-old) cows that received either adequate or marginal winter supplementation, there was poor predictability for the variation ($r^2 \leq 0.21$). When actual and predicted ADG for age and winter supplement treatment classification were tested, the 1996 Beef NRC predicted that cows would lose BW when they actually gained BW ($P \leq 0.03$; Table 3). Similar responses to DIP and MP were observed, as previously discussed, when MOEF was adjusted. In ad-

**Table 2.** Predicted nutrient balances and ADG from weaning to precalving (»139 d) compared with observed ADG for 3- and 7-yr- old Line 1 Hereford cows receiving 1.6 kg/d of a 24% CP alfalfa hay grazing winter range (6.7% CP, 50.5% TDN, 67.5% NDF) from weaning to precalving (»139 d) at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory, near Miles City, MT

| Cow age, yr | 1996 Beef NRC predictions[1] MOEF, % | Intake, kg/d | DIP balance, g/d | MP balance, g/d | $NE_m$ balance, Mcal/d | ADG, kg/d | Actual ADG, kg/d | SEM | *P*-value |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 8 | 11.01 | 430.25 | –86.8 | 2.09 | 0.04 | 0.27 | 0.06 | 0.01 |
| 3 | 13 | 11.01 | 251.19 | 27.9 | 2.09 | 0.04 | 0.27 | 0.06 | 0.01 |
| 7 | 8 | 12.29 | 462.70 | –86.8 | 2.44 | 0.09 | 0.06 | 0.10 | 0.81 |
| 7 | 13 | 12.29 | 265.38 | 39.7 | 2.44 | 0.09 | 0.06 | 0.10 | 0.81 |

[1]Predictions derived from the Beef NRC (NRC, 1996). MOEF = microbial efficiency of protein synthesis; DIP = degradable intake protein.

dition, we evaluated results from Waterman et al. (2006) for young lactating cows in a southwestern production system and observed poor agreement with actual vs. predicted 1996 Beef NRC ADG. The Beef NRC predicted the young lactating cows would lose 1.26 kg/d, whereas cows actually only lost 0.7 kg/d.

The data sets used to test the model provided by Fort Keogh LARRL come from populations of animals that have been managed similarly for multiple years. Both herds (Line 1 and CGC) are closed herds, which mean no outside genetics have been introduced since their origin, and this effect may not be fully elucidated in the current analysis.

### *Factors Influencing Synchrony of Predictions and Outcomes*

The predictability of any model is only as good as the information available and used in its construction. The 1996 Beef NRC was a huge advancement over previous installments, providing a means to evaluate diet composition and project future animal performance. Reviewed literature and new data presented within this paper demonstrate that there is a need to improve model accuracy for predicting animal performance, specifically in relation to compensatory gain and beef cattle grazing mature senescent rangelands in arid and semiarid environments. Factors that influence the synchrony of predictions and outcomes generated by the Beef NRC model include 1) the accuracy of feedstuffs in the feed library that includes the composition of each nutrient and their degradability,

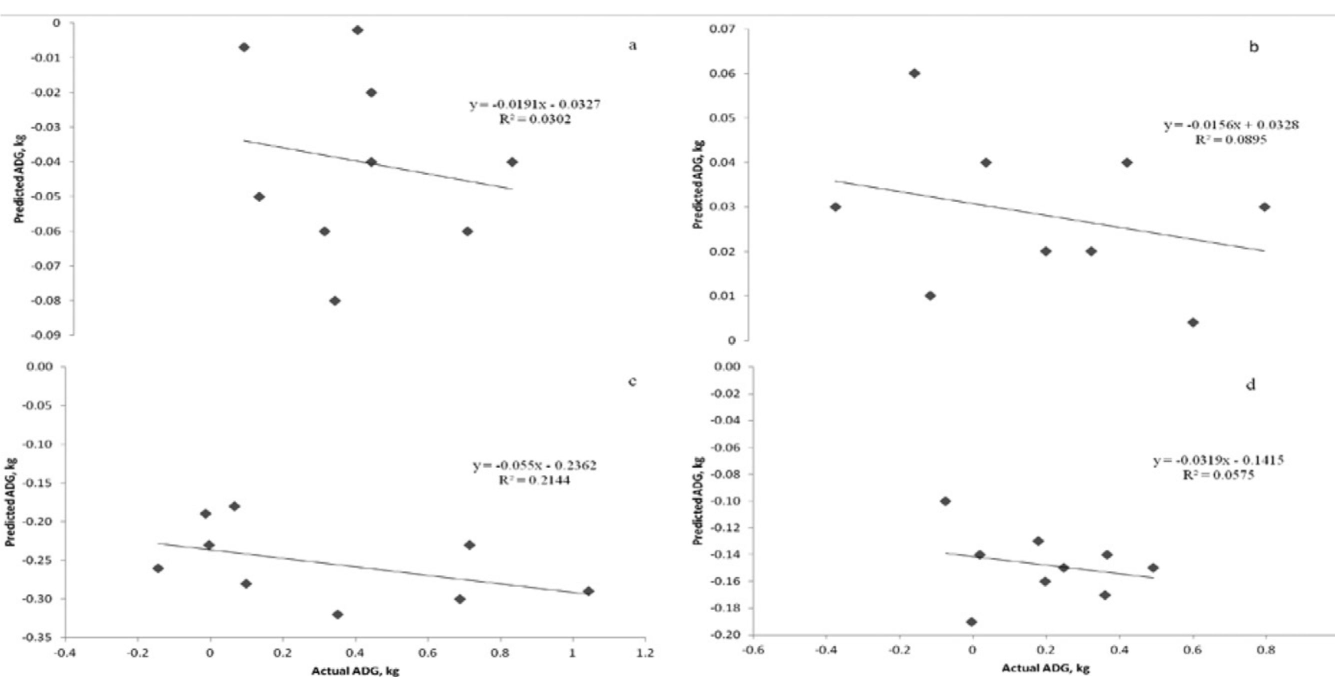


**Figure 2.** Regression of mean ADG from initiation of winter feed to precalving (≈ 97 d) predicted by the 1996 Beef NRC model on actual ADG for (a, c) 3-yr-old and (b, d) 7-yr-old Composite Gene Combination (CGC) beef cows over a 9-yr period at Fort Keogh Livestock and Range Research Laboratory near Miles City, MT. (a, b) Adequately supplemented cows received an equivalent of 1.81 kg/d, and (c, d) marginally supplemented cows received an equivalent of 1.09 kg/d of a 24% CP alfalfa hay while grazing dormant winter range (6.7% CP, 50.5% TDN, 67.5% NDF). Supplement was provided on a prorated basis every other day.

**Table 3.** Predicted nutrient balances and ADG from initiation of winter feed to precalving (≈ 97 d) compared with observed ADG for 3- and 7-yr- old Composite Gene Combination (CGC) cows grazing winter range at the USDA-ARS Fort Keogh Livestock and Range Research Laboratory, near Miles City, MT

| | 1996 Beef NRC predictions[2] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cow age and TRT[1] | MOEF, % | Intake, kg/d | DIP balance, g/d | MP balance, g/d | NEm balance, Mcal/d | ADG, kg/d | Actual ADG, kg/d | SEM | *P*-value |
| 3A | 8 | 10.5 | 629.4 | –68.7 | -0.19 | -0.04 | 0.38 | 0.06 | <0.01 |
| 3M | 8 | 10.5 | 269.0 | -119.9 | -1.13 | -0.25 | 0.31 | 0.10 | <0.01 |
| 3A | 13 | 10.5 | 125.9 | 53.4 | -0.19 | -0.04 | 0.38 | 0.06 | <0.01 |
| 3M | 13 | 10.5 | 109.8 | -18.0 | -1.13 | -0.25 | 0.31 | 0.10 | <0.01 |
| 7A | 8 | 11.9 | 350.9 | –69.7 | 0.14 | 0.03 | 0.29 | 0.08 | 0.03 |
| 7M | 8 | 11.9 | 303.2 | -120.6 | -0.77 | -0.15 | 0.20 | 0.05 | <0.01 |
| 7A | 13 | 11.9 | 140.7 | 65.0 | 0.14 | 0.03 | 0.29 | 0.08 | 0.03 |
| 7M | 13 | 11.9 | 124.5 | –6.11 | -0.77 | -0.15 | 0.20 | 0.05 | <0.01 |

[1]Where treatments (TRT) are adequately supplemented cows (A) receiving an equivalent of 1.81 kg/d and marginally supplemented cows (M) receiving an equivalent of 1.09 kg/d of a 24% CP alfalfa hay while grazing dormant winter range (6.7% CP, 50.5% TDN, 67.5% NDF). Supplement was provided on a prorated basis every other day.

[2]Predictions derived from the Beef NRC (NRC, 1996). MOEF = microbial efficiency of protein synthesis; DIP = degradable intake protein.

2) the stationary nature of the model, which does not have the ability to adjust for changes that occur over a specific interval of time, 3) the inclusion of region and geographical site-specific inputs that correct the model to improve predictions (e.g., climate, forage type [nutrient characteristics], terrain, etc.) with the corresponding stage of production, which were attempted in the 1996 model yet fail to be fully useful, 4) the inability to account for N recycling supplied by prorated delivery of strategic or targeted supplementation regimes, 5) the lack of consideration for the fate of MP once taken up by the host ruminant (e.g., used for energy or protein accretion), and 6) the inability of the model to adjust or reset maintenance requirements when animals are experiencing BW loss.

## SUMMARY AND CONCLUSIONS

A well-developed MP system should more accurately meet the demands for both microbial protein synthesis and for host animal AA demand. Other non-beef-cattle industries, such as swine and poultry, and recent approaches for dairy cows have realized significant increases in efficiencies of feed utilization with transitions from CP to an absorbable (MP) or more ideal protein-based system. Additionally, using a MP model to increase synchrony between protein supply and demand should, at least theoretically, result in reduced environmental nutrient load. Recognizing that there may not be adequate scientific data to fully address all concerns outlined in the present discussion, this review of the current 1996 Beef NRC has provided evidence for the need to direct future research that would provide relevant data to aid future modeling efforts for the Beef NRC.

In addressing our objective, which was to identify areas within the current Beef NRC that could be refined so that future Beef NRC models would have greater precision predicting protein supply and demand for beef cattle production within extensive grazing systems, we come to the following conclusions: 1) the current 1996 Beef NRC does not adequately account for plasticity and adaptability of the mature beef cow within arid and semiarid range conditions. 2) Additional work in the area of microbial efficiency in grazing beef cattle would increase our understanding and likely enhance model development. 3) N recycling data from well-adapted beef cows consuming lower-quality forages is needed, and N recycling concepts should be incorporated into the model. 4) Relative DIP and MP requirements for grazing cattle in extensive arid and semiarid environments are unreliable using the current Beef NRC, and direct in vivo measures of DIP and UIP from grazing cattle in general and cows specifically are sparse in the literature. 5) An improved ability to incorporate differing supplements and supplementation strategies into the model could improve the effectiveness and usability within extensive grazing systems, and 6) the area of developmental programming in response to MP supply coupled with potential metabolic effects of rumen-protected AA also warrants further consideration.

In addressing our second objective, which was to demonstrate strengths and weaknesses of the model in terms of predicting extensive range beef cow performance within arid and semiarid environments in the western United States, we conclude the following. Currently, the MP portion of the 1996 Beef NRC model functions as a calculator with no direct feedback influencing animal performance predictions. There is 1 exception with young growing animals (e.g., heifer development) where MP allowable gain is predicted; however, this prediction does not carry over once a cow enters gestation or lactation. There is a great opportunity to account for MP supply and/or absorption and partitioning of N as either going toward energy use or protein accretion. Second, for heifers being developed on native range, in late winter to early spring, the current Beef NRC model does not accurately adjust for compensatory gain, and consequently, the accuracy of the model prediction is poor. Third, there is a need for more extensive regionally based nutrient composition data for grazed forage. Finally, there is overall poor predictive agreement between the existing Beef NRC model and actual performance data for range beef cows produced in extensive arid and semiarid rangelands in the western United States, which is likely driven by the aforementioned factors.

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