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Building beef cow nutritional programs with the 1996 NRC beef cattle requirements model[1,2,3]

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ABSTRACT: Designing a sound cow-calf nutritional program requires knowledge of nutrient requirements, diet quality, and intake. Effectively using the NRC (1996) beef cattle requirements model (1996NRC) also requires knowledge of dietary degradable intake protein (DIP) and microbial efficiency. Objectives of this paper are to 1) describe a framework in which 1996NRC-applicable data can be generated, 2) describe seasonal changes in nutrients on native range, 3) use the 1996NRC to predict nutrient balance for cattle grazing these forages, and 4) make recommendations for using the 1996NRC for forage-fed cattle. Extrusa samples were collected over 2 yr on native upland range and subirrigated meadow in the Nebraska Sandhills. Samples were analyzed for CP, in vitro OM digestibility (IVOMD), and DIP. Regression equations to predict nutrients were developed from these data. The 1996NRC was used to predict nutrient balances based on the dietary nutrient analyses. Recommendations for model users were also developed. On subirrigated meadow, CP and IVOMD increased rapidly during March and April. On native range, CP and IVOMD increased from April through June but decreased rapidly from August through September. Degradable intake protein (DM basis) followed trends similar to CP for both native range and subirrigated meadow. Predicted nutrient balances for spring- and summer-calving cows agreed with reported values in the literature, provided that IVOMD values were converted to DE before use in the model (1.07 × IVOMD – 8.13). When the IVOMD-to-DE conversion was not used, the model gave unrealistically high NE_m balances. To effectively use the 1996NRC to estimate protein requirements, users should focus on three key estimates: DIP, microbial efficiency, and TDN intake. Consequently, efforts should be focused on adequately describing seasonal changes in forage nutrient content. In order to increase use of the 1996NRC, research is needed in the following areas: 1) cost-effective and accurate commercial laboratory procedures to estimate DIP, 2) reliable estimates or indicators of microbial efficiency for various forage types and qualities, 3) improved estimates of dietary TDN for forage-based diets, 4) validation work to improve estimates of DIP and MP requirements, and 5) incorporation of nitrogen recycling estimates.

Key Words: Cattle, Degradable, Forage, Grazing, Metabolizable, Protein

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Introduction

Beef cattle operations in the Great Plains use native range forages during much of the year. Native range in this area consists largely of a mixture of cool- and warm-season native species (Holecheck et al., 1989). Supplementation costs could be reduced with better information regarding nutrient supply and requirements (McCollum and Horn, 1990; Caton and Dhuyvetter, 1997).

The NRC (1996) Beef Cattle Requirements Model (**1996NRC**) represents a significant change in the expression of protein requirements. The model acknowledges that ruminal microorganisms have protein requirements that are different from host animal requirements. Degradable intake protein (**DIP**) is the fraction of the total protein that is ruminally degraded and is the primary source of nitrogen for the microorganisms. Metabolizable protein (**MP**) is the sum of the digestible

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bacterial protein and undegraded intake protein (**UIP**) present in a feedstuff. The model uses dietary TDN and microbial efficiency to determine DIP requirements.

To accurately estimate DIP and MP supply, the 1996NRC requires reliable estimates of TDN, DIP, UIP, DMI, and microbial efficiency. Forage quality changes with advancing season (Powell et al., 1982; McCollum et al., 1985; Adams et al., 1987). However, information on seasonal changes in DIP and UIP content of native range in the northern Great Plains is limited.

Objectives of this paper are to 1) describe a framework in which 1996NRC applicable data can be generated, 2) describe seasonal changes in nutrient quality including DIP and UIP on native range, 3) use the 1996NRC to predict nutrient balance for cattle grazing these forages, and 4) make recommendations for using the 1996NRC in building nutritional programs for forage-fed cattle.

Materials and Methods

Forage Characterization

Chemical composition and digestibility data were collected on forages commonly available for grazing beef cows in the Nebraska Sandhills. The majority of the research described herein was conducted on native range and subirrigated meadow at the University of Nebraska-Lincoln Gudmundsen Sandhills Laboratory, near Whitman, Nebraska. Diet samples were collected throughout the year in both 1992 and 1994. Weather data were collected concurrently at a weather station located approximately 11 km northeast of the ranch. In most cases, esophageally fistulated cows were used for collection, but some samples were collected using ruminally evacuated steers. A complete list of sampling dates and sample collection methods was outlined by Lardy (1997).

Rangeland at the Gudmundsen Sandhills Laboratory is generally composed of choppy sands. Dominant grass species on the native upland range sites were as follows: little bluestem (*Schizachyrium scoparium* [Michx.] Nash), prairie sandreed (*Calamovilfa longifolia* [Hook.] Scribn.), sand bluestem (*Andropogon gerardii* var. *paucipilus* [Nash] Fern.), switchgrass (*Panicum virgatum* L.), sand lovegrass (*Eragrostis trichodes* [Nutt.] Wood), indiangrass (*Sorghastrum nutans* [L.] Nash), and blue grama (*Bouteloua gracilis* [Willd. ex H.B.K.] Lag. ex Griffiths). Common forbs and shrubs include western ragweed (*Ambrosia psilostachya* DC.) and leadplant (*Amorpha canescens* [Nutt.] Pursh).

Subirrigated meadow soils were classified as Gannett-Loup fine sandy loam (course-loamy mixed mesic Typic Haplaquoll). Dominant vegetation on the subirrigated meadows consisted of smooth bromegrass (*Bromus inermis* Leyss), redtop (*Agrostis gigantea* Roth.), timothy (*Phleum pratense* L.), slender wheatgrass (*Elymus trachycaulus* [Link] Gould ex Shinners), quackgrass (*Elytrigia repens* [L.] Nevski.), Kentucky bluegrass (*Poa pratensis* L.), prairie cordgrass (*Spartina pectinata* Link), and several species of sedges (*Carex* spp.) and rushes (*Juncus* spp.). Less-abundant grass species were big bluestem (*Andropogon gerardii* var. *gerardii* Vitman), indiangrass (*Sorghastrum nutans* [L.] Nash), and switchgrass (*Panicum virgatum* L.). Abundant legumes included red clover (*Trifolium pratense* L.).

Extrusa samples were collected with four to seven cows or steers on each sampling date. Cows had been fitted with esophageal fistulas 2 to 4 yr before, as described by Adams et al. (1991) with modifications for adult cattle. Surgical preparations and postsurgical procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee. Steers had been fitted with ruminal fistula 1 yr before. Following an overnight fast, esophageally cannulated cows were equipped with screen-bottom bags and allowed to graze for 30 to 45 min. Extrusa samples were collected and frozen until laboratory analysis. Ruminally cannulated steers were also used to collect diet samples. Ruminal contents were evacuated and the ruminal wall of each steer washed with a sponge to remove remaining digesta and ruminal fluid. Steers were allowed to graze for approximately 45 min and diet samples were obtained via the ruminal cannula. All extrusa samples were freeze-dried (DM following freeze-drying ranged from 91 to 95%). Extrusa samples used for determining DIP were ground in a Wiley Mill to pass a 2-mm screen (Wilkerson et al., 1995). Samples used for remaining analysis were ground to pass through a 1-mm screen. Dry matter, organic matter, and CP of extrusa were determined by standard methods (AOAC, 1990); NDF was determined according to Van Soest et al. (1991); and ADF was determined by the method of Van Soest (1963). The in vitro organic matter disappearance (**IVOMD**) of extrusa samples was determined by the modified procedures of Tilley and Terry (1963) with the addition of 1 g of urea per liter of inoculum:buffer mixture (Weiss, 1994). The equations of Rittenhouse et al. (1971) were used to convert IVOMD to DE ($1.07 \times \text{IVOMD} - 8.13$).

Undegradable intake protein was calculated by the method of Mass et al. (1999). Five-gram samples (DM basis) were incubated in dacron bags (Ankom, Inc., Fairport, NY). Samples deemed vegetative were incubated for 4, 10, and 16 h; samples from dormant vegetation were incubated for 8, 16, and 24 h. Three separate incubation sequences were performed over 3 d. Bags were washed according to Wilkerson et al. (1995) and residue was analyzed for NDF-N. Amounts of NDF-N remaining after incubation were log-transformed, and a rate of degradation calculated. Undegradable intake protein (**UIP**) was calculated using the following formula: $\text{UIP} = \text{B}[\text{k}_\text{p}/(\text{k}_\text{d}+\text{k}_\text{p})]$, where B is the pool size or potential UIP calculated from the intercept of the log transformation of degradation, k_p is the rate of passage, and k_d is the rate of degradation of NDF-N (modified from Broderick, 1994). Passage rates were determined in a separate research project at the Gudmundsen Sandhills Laboratory during the 1994 growing season (Lamb, 1996; data not shown). In 1992, 8 samples from native range and 9 from subirrigated meadow were used; in 1994, 12 samples from native range and 10 from subirrigated meadow were used (Lardy, 1997).

Crude protein, UIP, DIP, and IVOMD for both subirrigated meadow and native range were analyzed using the PROC REG procedures of SAS (SAS Inst., Inc., Cary, NC). For meadow samples, day of the year was the independent variable, with March 1 considered d 1. For range samples, day of the year was the independent variable, with April 1 considered d 1.

Forage Evaluation and Use of the 1996 NRC Model to Predict Nutrient Balances

The 1996NRC was used to predict nutrient balances in beef cows consuming these forages at various stages of the reproductive cycle using the following assumptions. Mature cow body weight was 500 kg. Peak milk production was 8.2 kg/d. Calving date was March 1 for spring-calving cows and July 1 for summer-calving cows. Weaning date was October 15 for spring-born calves and January 1 for summer-born calves. When meadow hay was included in rations, it was assumed to be of average quality (56% digestibility, 8% CP, 80% DIP; Villalobos, 1993). No supplemental energy or protein were included in the calculations. The DIP requirement was equal to digestibility × 0.13 for vegetative forages and digestibility × 0.10 for dormant forages, including meadow hay. Estimates of dry matter intake were based on predictions from NRC (1996). All calculations were made using thermoneutral conditions.

Results and Discussion

Climatic Conditions

During 1992, precipitation during April and May was 4.6 and 7.1 cm below normal, respectively. Total precipitation for the 1992 calendar year was 10.2 cm below normal. Average high temperatures in June, July, and August were 4 to 6°C below normal. In late May, two consecutive days of below-freezing overnight lows (–1 and –5°C) were recorded, which likely influenced grass growth and quality patterns. During 1994, temperatures and precipitation were average. Long-term average precipitation for this site is 53.5 cm annually, with 26.2 cm falling in May, June, and July (NSCO, 2003).

Forage Composition

In order to use the 1996NRC, data were averaged within months over sampling method and year. Table 1 shows the seasonal changes (means ± SD, where applicable) in chemical composition and DIP of subirrigated meadow diet samples collected during 1992 and 1994. Because the subirrigated meadow sites are cool-season

Table 1. Means and standard deviations of laboratory analysis of meadow diet samples collected at Gudmundsen Sandhills Laboratory, Whitman, Nebraska, in 1992 and 1994 (OM Basis)[a,b]

Date	Sample type[c]	No. of OBS	CP, % OM	NDIN, % OM	ADIN, % OM	UIP, % OM	DIP, % OM	NDF, % OM	ADF, % OM	IVOMD, %	Predicted DE, %[d]
Jan	Regrowth	1	12.1	0.76	0.12	1.4	10.7	77.2	50.2	53.4	49.0
Mar	Primary	1	16.6	0.91	0.22	1.2	15.4	66.8	42.4	60.2	56.2
Apr	Primary	1	29.4	0.92	0.03	4.2	25.3	49.3	27.3	68.3	64.9
May	Primary	1	17.6	1.09	0.17	3.1	14.5	73.0	42.3	68.3	65.0
Jun	Primary	3	17.3 ± 4.6	0.75 ± 0.13	0.13 ± 0.01	2.3 ± 0.4	15.0 ± 4.3	68.6 ± 12.0	39.2 ± 6.2	70.8 ± 5.5	67.6 ± 7.2
Jul	Primary	3	12.4 ± 2.7	0.67 ± 0.09	0.13 ± 0.04	2.0 ± 0.2	10.4 ± 2.6	72.0 ± 4.7	41.7 ± 4.7	66.0 ± 5.3	62.5 ± 6.9
Aug	Regrowth	2	17.2 ± 3.6	0.63 ± 0.18	0.08 ± 0.03	2.3 ± 0.8	14.8 ± 2.8	63.2 ± 11.6	44.4 ± 4.3	64.4 ± 4.4	60.8 ± 6.7
Sept	Regrowth	3	15.6 ± 1.7	0.67 ± 0.07	0.14 ± 0.03	1.8 ± 0.3	13.9 ± 1.5	70.52 ± 5.0	43.7 ± 4.6	63.4 ± 4.2	59.8 ± 5.5
Oct	Regrowth	1	14.9	0.68	0.14	1.3	13.6	63.8	44.1	67.7	64.3
Nov	Regrowth	1	9.1	0.48	0.23	1.2	7.9	78.6	53.8	47.5	42.7
Dec	Regrowth	2	8.1 ± 0.3	0.47 ± 0.01	0.19 ± 0.02	1.0 ± 0.1	7.0 ± 0.3	83.1 ± 0.7	55.8 ± 1.0	54.2 ± 1.9	49.9 ± 2.9

[a] No. of OBS = number of sampling dates analyzed for a given month; each observation represented four to seven diets collected by esophageally fistulated cows or ruminally cannulated steers; NDIN = neutral detergent = insoluble nitrogen; UIP = undegraded intake protein; DIP = degraded intake protein; IVOM = in vitro organic matter disappearance.

[b] Standard deviations listed are for averages of diets collected over 1992 and 1994 within each month, not for laboratory analysis within a particular sample collection.

[c] Sample type: Regrowth, growth following July haying; Primary, growth before July haying.

[d] Equations to convert IVOMD to DE adapted from Rittenhouse et al. (1971).

Table 2. Means and standard deviations of laboratory analysis of upland range diet samples collected at Gudmundsen Sandhills Laboratory in 1992 and 1994 (OM Basis)[a,b]

Sample date	No. of OBS	CP, % OM	NDIN, % OM	ADIN, %, OM	UIP, % OM	DIP, % OM	NDF, % OM	ADF, % OM	IVOMD, %	Predicted DE, %[c]
Jan	1	6.3	0.45	0.15	0.8	5.5	83.6	52.5	58.0	53.9
Mar	2	6.0 ± 0.2	0.48 ± 0.10	0.09 ± 0.05	1.0 ± 0.02	5.0 ± 0.3	82.5 ± 0.9	53.3 ± 0.2	54.8 ± 0.7	50.5 ± 1.1
Apr	2	11.4 ± 1.9	0.79 ± 0.05	0.11 ± 0.01	1.2 ± 0.1	10.2 ± 1.8	77.5 ± 5.3	43.2 ± 6.1	67.6 ± 9.3	64.2 ± 1.4
Jun	3	13.8 ± 2.5	0.85 ± 0.15	0.12 ± 0.02	2.5 ± 0.2	11.3 ± 2.4	72.4 ± 2.7	40.6 ± 2.5	67.6 ± 2.6	64.2 ± 3.4
Jul	4	12.3 ± 1.5	0.90 ± 0.06	0.14 ± 0.01	2.2 ± 0.3	10.1 ± 1.3	79.8 ± 3.6	43.6 ± 4.3	67.5 ± 2.4	64.1 ± 3.0
Aug	3	11.3 ± 2.5	0.79 ± 0.11	0.16 ± 0.02	1.8 ± 0.4	9.5 ± 2.3	77.9 ± 4.4	46.4 ± 4.3	63.7 ± 3.6	60.0 ± 4.8
Sept	2	7.4 ± 0.3	0.51 ± 0.06	0.12 ± 0.02	1.1 ± 0.2	6.4 ± 0.6	79.7 ± 1.3	48.8 ± 1.4	60.7 ± 1.2	56.8 ± 1.8
Nov	1	5.9	0.37	0.27	0.7	5.2	84.4	56.1	48.3	43.6
Dec	2	6.5 ± 0.6	0.39 ± 0.08	0.13 ± 0.06	1.2 ± 0.2	5.4 ± 0.4	86.0 ± 1.0	54.5 ± 0.4	53.9 ± 5.5	49.5 ± 8.3

[a] No. of OBS = number of sampling dates analyzed for a given month; each observation represents four to seven diets collected by esophageally fistulated cows or ruminally cannulated steers; NDIN = neutral detergent insoluble nitrogen; UIP = undegraded intake protein; DIP = degraded intake protein; IVOMD = in vitro organic matter disappearance.

[b] Standard deviations listed are for averages of diets collected over 1992 and 1994 within each month, not for laboratory analysis within a particular sample collection.

[c] Equations to convert IVOMD to DE adapted from Rittenhouse et al. (1971).

species with a small component of legumes, a rapid increase in CP and IVOMD in early spring should be expected. Growth begins in March, with rapid increases in CP occurring in April. Forage quality declines during mid-summer as temperatures increase and cool-season grasses cease growth. Regrowth occurs as temperatures decrease during the fall, and forage quality increases. Estimates of UIP were generally highest during periods of active growth. Olson et al. (1994) reported lower CP over the season compared with results reported here on subirrigated meadow. However, due to the subirrigated nature of the meadows, it is difficult to compare the two data sets because the native range used by Olson et al. (1994) was a mix of warm- and cool-season species.

Table 2 shows seasonal changes in chemical composition and DIP of native range diet samples. Native range sites are primarily warm-season species that grow rapidly during the summer months. Some cool-season species are present, which explains the relatively high forage quality in April, but forage quantity would not be expected to support heavy grazing at this time (Burzlaff, 1962; Nosal, 1983). Forage quality decreases rapidly on native Sandhills range as evidenced by the decline in CP during September. Similar declines in CP on short-grass prairie during the fall months were reported by Adams et al. (1987). In their work, dietary CP was higher during the early part of the growing season (May to June), but lower in CP later in the growing season than CP reported in this paper. Holechek et al. (1981) did not report decreases in CP to the magnitude of those reported herein on native range. Crude protein remained above 10% on Oregon grasslands during September and October in the study of Holechek et al. (1981), whereas native range diets in our study averaged 7.4% CP in September. Major grass species on the study site used by Holechek et al. (1981) included bluebunch wheatgrass (*Agropyron sipcatum* [Pursh] Scribn. & Sm.) and Sandberg bluegrass (*Poa secunda* Presl). Holechek et al. (1981) reported that precipitation was adequate to promote regrowth of grasses, which were relatively high in CP. Contrary to our results and in agreement with Holechek et al. (1981), Hirschfeld et al. (1996) reported higher CP during September and October on mixed-grass prairie in North Dakota. In our study, precipitation was below average in 1992 and average in 1994. However, due to the warm-season dominated nature of the native range grasses, decreases in CP would be expected as plants become dormant.

Yates et al. (1982) reported diet quality from two trials that evaluated the effect of continuous grazing on steer diets. Compared with our report, they reported lower CP and similar IVOMD in August. Their experiment was conducted on native Sandhills range at a site located about 80 km southeast of the present study site. In a second trial, Yates et al. (1982) examined the effects that continuous grazing had on diet quality during the winter on native range mixed prairie. Uplands at this site were dominated by blue grama [*Bouteloua gracilis* [Willd. ex H.B.K.] Lag. ex Griffiths), needle and thread (*Stipa comata* Trin & Rupr.), and thread leaf sedge (*Cares filifolia* Nutt.), whereas sharp breaks were dominated by little bluestem (*Schizachrium scoparium* [Michx.] Nash), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), and big bluestem (*Andropogon gerardii* var. *gerardii* Vitman). The site used by Yates et al. (1982) in the second study was located approximately 130 km southeast of our site. This site would not be considered similar to the native range used in our study because soil type and species composition were different. In general, values for CP and IVDMD were lower than those from our data.

Acid detergent fiber levels were higher than those reported by Adams et al. (1987) and similar to values reported by McCollum et al. (1985) on blue grama rangelands in New Mexico. Hirschfeld et al. (1996) reported higher NDF and ADF compared with our data from either subirrigated meadow or native range. Holechek et al. (1981) reported much higher ADF levels

Table 3. Regression equations for prediction of crude protein, undegradable intake protein, degradable intake protein, and in vitro organic matter digestibility of subirrigated meadow and native range samples

Nutrient[a]	Equation	R^2
	Subirrigated meadow samples[b]	
CP, % of OM	$1.523698 + 1.346704X - 0.024693X^2 + (1.77324 \times 10^{-4})X^3 - (5.54 \times 10^{-7})X^4 + (6.27927 \times 10^{-10})X^5$	0.651
UIP, % of OM	$-4.98141 + 0.543179X - 0.011468X^2 + (1.08125 \times 10^{-4})X^3 - (5.11525 \times 10^{-7})X^4 + (1.18228 \times 10^{-9})X^5 - (1.06095 \times 10^{-12})X^6$	0.835
DIP, % of OM	$2.97353 + 1.120967X - 0.021132X^2 + 0.00015405X^3 - (4.860933 \times 10^{-7})X^4 + (5.536177 \times 10^{-10})X^5$	0.633
IVOMD, % of OM	$65.141 + 0.053X - 0.0003067X^2$	0.477
	Native range samples[c]	
CP, % of OM	$11.119 + 0.06225Z - 0.00063Z^2 + (1.178 \times 10^{-6})Z^3$	0.660
UIP, % of OM	$0.2928 + 0.07675Z - 0.0008524Z^2 + (3.192 \times 10^{-6})Z^3 - (3.904 \times 10^{-9})Z^4$	0.823
DIP, % of OM	$9.996 + 0.03567Z - 0.0004267Z^2 + (8.169 \times 10^{-7})Z^3$	0.630
IVOMD, % of OM	$59.55 + 0.4661Z - 0.005776Z^2 + (2.193 \times 10^{-5})Z^3 - (2.665 \times 10^{-8})Z^4$	0.686

[a] CP = crude protein; UIP = undegraded intake protein; DIP = degraded intake protein; IVOM = in vitro organic matter disappearance.
[b] X = day after March 1.
[c] Z = day after April 1.

on both forested and grassland range in Oregon than we found on either subirrigated meadow (Table 1) or native range (Table 2). Olson et al. (1994) reported higher values for NDF and ADF compared with values reported here. Again in contrast to the data presented here, Fredrickson et al. (1993) reported higher NDF and ADF values for diets of steers grazing blue grama range in northeastern New Mexico from August through November. In their work, NDF and ADF tended to increase with advancing maturity, which agrees with the present data. Fredrickson et al. (1993) reported several factors that hastened the onset of dormancy in their study: 1) precipitation in July was 70% below normal, 2) low temperatures in November, and 3) low precipitation in October and November. This, coupled with differences in latitude and forage species, may explain why we found lower NDF and ADF than those authors.

In vitro organic matter disappearance followed the general pattern reported by McCollum et al. (1985) and Adams et al. (1987). In vitro organic matter disappearance values reported by Hirschfeld et al. (1996) were similar to values reported in this paper. The work of Hirschfeld et al. (1996) was conducted on sites dominated by blue grama, needle-and-thread, sedges, Kentucky bluegrass, and western snowberry. Holechek et al. (1981) compared diet quality from forested pastures to that of grassland pastures in Oregon. On forested pastures, those researchers found that IVDMD decreased with advancing plant maturity and were in general agreement with data we report for native range.

Undegradable intake protein content of samples collected from native range was also greatest during periods of active growth. This is a function both of a larger NDF-N pool size with the potential to escape and faster passage rates (data not shown). Degradable intake protein increased during active growth and declined during dormancy in a manner similar to that of CP. This may be expected because DIP levels, when expressed as a percentage of the CP, were greater than 80%. Olson et al. (1994) found that insoluble N generally declined with advancing season. One could expect measures of insoluble nitrogen to follow the same general trends as NDF-N. Neutral detergent fiber-N was least for dormant samples and greatest for actively growing forages in our study. This finding is in agreement with the work of McCollum et al. (1985). Acid detergent-insoluble nitrogen values are in agreement with those reported by Olson et al. (1994) for steers grazing native range in North Dakota.

Regression equations for prediction of CP, UIP, DIP, and IVOMD for subirrigated meadow and native range are presented in Table 3. Forage growth on subirrigated meadow begins in March; therefore, d 1 in the regression equations for subirrigated meadow is March 1. The best-fit regression equations for these variables ranged from second- to sixth-degree polynomial equations, with R^2 values ranging from 0.477 to 0.835. Based on R^2, the best estimation equation was for prediction of UIP. Adams and Short (1987) reported slightly higher R^2 values for prediction of CP and ME content of diets collected on northern Great Plains rangelands in Montana. The data used by Adams and Short (1987) included 78 samples, whereas the data reported here used 19 samples.

The best-fit regression equations for native range samples for these same variables ranged from third- to fourth-degree polynomial equations, with R^2 values ranging from 0.630 to 0.823 (Table 3). For upland range regression equations, April 1 was considered d 1. The estimation equation with the highest R^2 value was for prediction of UIP. Adams and Short (1987) reported slightly higher R^2 values for predicting dietary CP and ME content from northern Great Plains rangelands, a finding that is most likely due to the number of samples used, as discussed previously.

Forage Evaluation and Use of the 1996 NRC Model to Predict Nutrient Balances

Table 4 shows the consequence of changes in microbial efficiency on estimated DIP and MP supply, re-

Table 4. Effect of microbial efficiency on degradable and metabolizable protein requirement, supply, and balance for a gestating spring-calving cow consuming dormant winter range

	Microbial efficiency, %					
Item[a]	8	9	10	11	12	13
DIP supply, g/d	518	518	518	518	518	518
DIP requirement, g/d	422	475	528	581	633	686
DIP balance, g/d	96	43	–10	–62	–115	–168
MP supply, g/d	355	388	422	456	490	524
MP requirement, g/d	470	470	470	470	470	470
MP balance, g/d	–116	–82	–48	–14	20	54

[a] DIP = degraded intake protein; MP = metabolizable protein.

quirement, and balance for gestating, spring-calving cows that were grazing native winter range. Microbial efficiency can range from 8 to 13%. Values as low as 8% can be expected with low-quality forages (< 60% digestibility; NRC, 1996). With slow passage rates, more energy is used by the ruminal microbes for maintenance, including cell lysis (NRC, 1996). Data collected on dormant winter range in Nebraska would suggest that this range of efficiencies is reasonable (Villalobos, 1993; Hollingsworth-Jenkins et al., 1996). As microbial efficiency is reduced from 13% to 8%, DIP balance moves from highly negative to slightly positive. At the same time, MP balance goes from positive to highly negative. The consequence of choosing an efficiency that is too high would be to oversupplement DIP and to overestimate the supply of MP available to the animal. The consequence of choosing an efficiency that is too low would be to underestimate the DIP requirement and fail to supplement DIP when supplementation is necessary (NRC, 1996). In addition, one would conclude that MP was deficient at 8% microbial efficiency, when in fact it is not. Hollingsworth-Jenkins et al. (1996) estimated DIP requirements for spring-calving cows grazing native winter range. They measured deficiencies ranging from approximately 60 to 140 g of DIP daily. This is also in general agreement with Köster et al. (1996), who estimated DIP requirements at 11% of digestible OM intake for cows consuming low-quality tallgrass prairie forage. Scott and Hibberd (1990) fed cows 4% CP native grass hay supplemented with increasing DIP level. They found that forage digestion and intake were maximized at DIP levels of 9% of rumen digestible OM. Based on the data presented above, we chose to use 10% and 13% microbial efficiency values for dormant and growing forages, respectively, for our nutrient balance calculations (Tables 5 and 6).

Table 5 shows the nutrient balances for spring-calving cows. The 1996NRC predicted energy deficiencies when lactating spring-calving cows were fed meadow hay. Metabolizable protein was deficient when lactating cows were fed meadow hay and when gestating cows grazed winter range. Degradable intake protein deficiencies were predicted when cows grazed dormant winter range. Predicted deficiencies are lower than in vivo deficiencies determined by Hollingsworth-Jenkins et al. (1996) for gestating spring-calving cows grazing dormant winter range in the Nebraska Sandhills. Those authors reported that cows lost body condition during

Table 5. Nutrient balances for a spring-calving cow as predicted by the NRC (1996) model[a]

	Diet													
	Meadow hay		Meadow grazing		Native range				Meadow grazing		Native range		Meadow hay	
Item[b]	Apr	May	May	Jun	Jun	Jul	Aug	Sep	Sep	Oct	Dec	Jan	Feb	Mar
Microbial efficiency, %	10	10	13	13	13	13	13	13	13	13	10	10	10	10
NE_m available, Mcal/d	13.6	13.6	18.4	19.8	17.9	17.4	15.0	13.2	14.6	16.5	10.1	12.1	12.8	13.0
NE_m required, Mcal/d	16.5	16.1	16.1	14.8	14.8	13.5	12.6	12.3	12.3	9.3	11.2	12.2	13.3	14.4
NE_m balance, Mcal/d	–2.9	–2.5	2.3	5.0	3.1	4.0	2.4	0.9	2.3	7.2	–1.0	–0.1	–0.5	–1.4
MP available, g/d	563	563	955	927	885	835	720	598	695	713	422	442	530	536
MP required, g/d	823	825	825	761	761	682	611	556	556	417	453	493	556	634
MP balance, g/d	–260	–263	129	166	124	153	109	42	139	296	–31	–51	–26	–98
DIP available, g/d	740	740	1,627	1,718	1,260	1,097	977	632	1,402	1,388	518	544	697	706
DIP required, g/d	648	648	1,054	1,118	1,034	1,006	892	811	871	948	528	592	610	617
DIP balance, g/d	93	93	572	600	226	91	85	–178	531	440	–10	–48	87	88
DMI, kg/d	11.6	11.6	12.5	12.8	12.4	12.1	11.5	11.0	11.2	11.4	10.7	11.0	10.9	11.0

[a] Calving date for spring-calving cows was March 1.

[b] MP = metabolizable protein; DIP = degradable intake protein.

Table 6. Nutrient balances for a summer-calving cow as predicted by the NRC (1996) model[a]

	Diet											
	Native range			Meadow grazing				Native range				
Item[b]	Jul	Aug	Sep	Sep	Oct	Nov	Dec	Nov	Dec	Jan	Mar	Jun
Microbial efficiency, %	13	13	13	13	13	10	10	10	10	10	10	13
NE$_m$ available, Mcal/d	16.3	15.2	13.6	15.1	18.5	6.6	11.2	7.1	10.9	12.1	10.9	16.0
NE$_m$ required, Mcal/d	12.8	15.5	15.9	15.9	15.5	15.0	14.5	15.0	14.5	10.2	10.2	11.7
NE$_m$ balance, Mcal/d	3.5	–0.3	–2.3	–0.8	3.0	–8.4	–3.3	–7.9	–3.6	1.9	0.7	4.3
MP available, g/d	782	731	618	720	801	336	463	318	453	442	438	787
MP required, g/d	634	823	825	825	761	682	611	682	611	409	430	556
MP balance, g/d	148	–92	–208	–105	40	–345	–148	–363	–158	33	8	232
DIP available, g/d	1,027	996	653	1,453	1,560	664	732	452	556	592	498	1,121
DIP required, g/d	941	906	838	903	1,066	399	580	421	566	544	559	920
DIP balance, g/d	86	86	–184	550	495	265	152	31	–10	–48	–61	201
DMI, kg/d	11.3	11.6	11.4	11.6	12.8	9.4	11.6	9.7	11.5	11.0	11.1	11.0

[a] Calving date for summer-calving cows was July 1.

[b] MP = metabolizable protein; DIP = degradable intake protein.

the winter. This is reflected in the application of our data from December and January with the 1996NRC, which predicts small energy deficiencies during those time periods.

When IVOMD was used as a proxy for TDN in the 1996NRC model runs (data not shown), energy balance was overpredicted. A companion abstract from this symposium discusses these efforts more extensively (Patterson and Klopfenstein, 2003).

For summer-calving cows (Table 6), predicted deficiencies in energy were common when lactating cows grazed dormant fall-winter forages for either meadow or native range. Predicted MP deficiencies were also common when lactating cows grazed dormant range or subirrigated meadow. Predicted DIP deficiencies were also common on dormant fall and winter range. This is in agreement with cow performance data gathered using summer-calving cows grazing native range during the fall and winter and fed either DIP or DIP plus UIP supplements (Lardy et al., 1999). Those trials indicated that DIP and UIP were co-limiting for lactating summer calving cows grazing dormant native range during the fall and winter. In addition, DIP seems to be limiting for gestating, summer-calving cows grazing dormant winter range (Lardy et al., 1997). This is in agreement with our model calculations using dormant winter diets. Predicted energy deficiencies for summer-calving cows grazing native range or subirrigated meadow in November appear to be unreasonable (–7.9 and –8.4 Mcal/d, respectively). The low balances are a function of low energy concentrations predicted using the equations of Rittenhouse et al. (1971) and the low DMI predictions that result. The combination of low energy and DMI resulted in predicted energy deficits that are biologically unreasonable. The diet data collected in November for both subirrigated meadow and native range are based on only one sampling date. The low number of samples may contribute to the problem. As data sets such as this are developed for other areas of the country, focus should be on compiling several years' worth of data to minimize year-to-year variation.

Table 7 gives suggested input guidelines for using the 1996NRC for grazing beef cows. This is intended as a guideline for county and area extension educators, feed industry personnel, and others who might use the computer model to evaluate diets for grazing cattle. More detail on various aspects of using the model can be found in the NRC (1996) text. In some cases, users should be cautious when using some of the model features and interpreting output if these features are used. The most significant finding in this regard is the sensitivity of the model to environmental inputs. Users are urged to focus on long-term average temperatures for a particular time period. In addition, wind speed inputs should also be limited to 8 km/h or less. Values greater than this will unrealistically impact energy balances. In addition, our recommendation is that the "On Pasture" feature in the model not be used because it unrealistically increases energy requirements. In almost all cases, if the feature is not used, model output data more closely resembles biological data gathered at field stations. For instance, for the spring-calving cow grazing native range in December, with the On Pasture feature not in use, the predicted NE$_m$ balance is –1.0 Mcal/d (Table 5). However, if the On Pasture feature is used with level terrain, a NE$_m$ balance is –5.4 Mcal/d is predicted (data not shown). If the Hilly Terrain feature is used, the NE$_m$ balance is –6.7 Mcal/d, a biologically unreasonable value. Therefore, we recommend that the On Pasture feature not be used.

The model predicted that MP balance is sensitive to DMI, supplement degradability, and microbial efficiency (Lalman and Lardy, 1998). For DIP balance, the critical model inputs appear to be microbial efficiency and supplement DIP. In addition, the methodology used to estimate forage DIP also impacts sensitivity. For instance, methods that estimate lower forage DIP generally have greater impacts on DIP supply. This is logi-

Table 7. Suggested inputs and guidelines for use of the NRC (1996) model

Units and Levels Section	
	Use only Level 1, unless the user has the digestion rates for feed fractions well characterized.
Animal Section	
A.	**Breed Effects.** The choice of breed affects maintenance energy requirements and the default levels of milk production that will be used in the model. Users should review the NRC (1996) text to determine which breed choices are most appropriate for a given situation. *Bos indicus* cattle have lower NE_m requirements, whereas dairy and dual-purpose breeds have higher requirements.
B.	**Effect of Age on Milk Production.** The NRC Model will adjust milk production based on the age of cow (for 2- and 3-yr-old cows). The adjustment factor is 0.74 for 2-yr-old cows and 0.88 for 3-yr-old cows. Because the NRC Model makes this adjustment automatically, no adjustment in peak milk production is necessary based on age of cow.
Management Section.	
A.	Using the **On Pasture** feature in the management section will increase maintenance energy requirements by approximately 25% with level terrain and by 50% with hilly terrain. The value can be input as a range between 1 (level) and 2 (hilly) in 0.1-unit increments. We recommend this feature not be used in most situations. In most cases, maintenance energy requirement is not increased by 25% when cattle are on pasture.
B.	**Microbial Yield.** Use 13% (default) for all vegetative forages and forages above 60% digestibility. For lower quality forages, such as winter range, use a microbial efficiency of 9 to 10%. Values as low as 8% may be necessary when the diet consists of mainly straw, stover, or other forages below 50% TDN, which have lower passage rates.
Environment Section	
A.	**Temperature.** Daily temperatures fluctuate. In addition, interactions also exist with other environmental factors, which are discussed below. Use long-term average temperatures for a given month or season at a given location.
B.	**Wind Speed.** Caution is needed when using this feature. Because cattle behavior is impacted by wind speed, cattle may not be subjected to reported wind speeds. Wind speed is generally measured by anemometers positioned 3.1 m above ground surfaces. Cattle are seldom subjected to these wind speeds because they will find ways to minimize the effect of wind on them. We recommend using wind speeds of less than 8.3 km/h in most cases.
C.	**Hair Depth.** Use 0.64 cm in the summer and 1.27 cm for winter coats.
D.	**Hide.** Use 1 (thin hide) for *Bos indicus* and dairy breed types, and 2 (average) or 3 (thick) for most English and Continental breeds.
Feeds Section	
A.	Use the **Feed Library** (a feature separate from the model) to make global changes to feedstuff composition. Use the **Feed Composition** feature to make feed composition changes specific to a ration or problem (composition changes made in this manner will be specific to that input file only).
B.	When estimates of feed intake are unavailable or unknown, use the NRC estimated intake as a guideline. Use the following as general guidelines. Dry gestating cows will generally consume 1.8 to 2.0% of BW, whereas lactating cows will consume 2.3 to 2.5% of BW.
C.	Estimates of TDN are very important. Not only does the model use dietary TDN to predict performance (converted to net energy), but TDN also impacts DIP requirements and MP supply. If estimates of TDN intake are incorrect, estimated DIP requirements and MP supply also will be incorrect.

cal from a mathematical standpoint because methods that estimate lower forage DIP would lead to lower estimates for DIP balance.

An accurate estimate of TDN intake is critical for accurate model prediction of grazing cows' performance and the prediction of DIP requirements and MP supply. Supplementation can affect digestibility of the forage, either positively or negatively (Moore et al., 1999); however, we did not attempt to model this response.

Recommendations to Extension Specialists to Improve Adoption of the MP System

Beef cattle extension specialists should look for additional opportunities to train extension educators to help them become comfortable with the MP system. These may include specialized workshops or in-service training, distance education opportunities, or simply incorporation of the MP system into routine programming efforts. In addition, extension specialists should also focus on development of state-specific feed libraries for use in the 1996NRC model. This is relatively easy to do and would emphasize the importance of the model in developing nutritional programs.

Recommendations to Scientists with Interest in Beef Cattle Nutrition and Management

There are many areas of potential research contained within the framework of the 1996NRC. The most obvious of these appears to be the need for a greater understanding of factors influencing microbial efficiency and the use of appropriate measurement methods. In addition, scientists should focus attention on data reporting. This will enhance the ability of the next NRC committee to properly evaluate and use data to generate requirements. Data needed include development of forage databases, as well as reporting interim weights, condition scores, DMI, environmental conditions, and other data that are used in the 1996NRC.

Recommendations to Future NRC Beef Cattle Nutrient Requirement Committees

The NRC (1996) publication represented a significant move forward in the understanding of protein nutrition in beef cattle. The use of a computer model to generate requirements also represents a significant contribution to the needs of the industry. However, the lack of acceptance of the current edition of the NRC requirements, is partially driven by the fact that the software package is not Microsoft Windows-based. Consequently, future committees should strongly consider the development of a Windows-based computer model for the next edition. In addition, further incorporation of the effect of environment also is needed.

Implications

The computer model in the 1996 NRC *Nutrient Requirements of Beef Cattle* publication is a useful tool for predicting supplement needs when reliable information regarding protein degradabilities and diet digestibilities are available. In our data, subirrigated meadow increased in nutrients rapidly in the spring and remained higher in quality during the fall, compared with native range. Native range samples were highest in quality during the warmer summer months. Undegradable intake protein, for both subirrigated meadow and native range, was highest during periods of active growth. Beef cows are maintained on a wide variety of forages throughout the United States. Future research efforts should focus on generating additional data for protein degradabilities and microbial efficiency of grazed and harvested forages. In addition, extension programming efforts for extension educators should be focused on increasing knowledge of the metabolizable protein system and its application to the grazing beef cow.

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