APPLICATION OF THE CORNELL NET CARBOHYDRATE AND PROTEIN SYSTEM FOR PREDICTING THE NUTRIENT REQUIREMENTS OF BEEF CATTLE

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INTRODUCTION

Accurate evaluation of animal performance and feed utilization is dependent on being able to describe and predict the effects of most of the significant variables that will influence requirements and nutrients available to meet requirements for a particular group of cattle in the environment in which they are being fed. Every farm has a unique combination of animal, environmental, feed and management factors. We utilize over 100 genotypes of cattle with a continuum of milk and growth potential in nearly every climatic extreme existing, then superimpose a wide variety of nutritional and management systems in utilizing available resources. To make further improvements in performance and feed efficiency, we must move beyond applying requirements determined under standardized conditions and generalized values of feed carbohydrate and protein to specific combinations of animal, management and environmental situations. The use of mechanistic, validated models that can be driven by observable and measurable inputs, and can be adjusted to the unique conditions under which they will be applied, are necessary to accurately formulate rations across widely varying conditions.

The previous paper in this proceedings on the application of the Cornell Net Carbohydrate and Protein System (CNCPS) for Feeding Dairy Cattle contained a summary of the components of this model and how to adjust its animal and dietary inputs to predict animal performance in each unique production setting. For details of model development and validation the reader is referred to Russell et al. (1992), Sniffen et al. (1992), Fox et al. (1992), O'Connor et al. (1993), Ainslie et al. (1993), Tylutki et al.(1994) and Fox et al. (1995). The purpose of this paper is to present a summary of the applications we have made of the CNCPS predicting nutrient requirements and utilization for beef cattle under widely varying conditions.

APPLICATIONS OF THE CORNELL NET CARBOHYDRATE AND PROTEIN SYSTEM

We have used the CNCPS in various ways as tools to improve the performance of beef cattle. Roseler (1991) has summarized our experiences in applications of computer models for the feed industry. The following summarizes our experiences with these uses.

1. **As a teaching tool to improve the skills of consultants and advisors in adjusting for the interactions of feed composition, feeding management and animal requirements with varying farm conditions.** A major role of consultants (nutritionists, veterinarians, extension, etc.) is to diagnose feeding and management problems or to determine weak links. Observational skills are extremely important. Over the years, my colleagues and I have used computer models in training sessions for many individuals and groups to teach responses of cattle to widely varying animal, management, feed and environmental conditions and the economic impact of various variables. Over the past two years we held several two-day workshops on the biological basis of our CNCPS and its use in the field for extension agents, private consultants, and feed company nutritionists and technical representatives. Those who participated indicated that one of the most important uses of the CNCPS would be to improve their diagnostic skills through having a better understanding of the animal, feed and environmental interactions on a particular farm.

2. **Development of adjustments for variations in animal requirements.** Our models

Table 1. Maintenance requirement multipliers for representative environmental conditions[a,b]						
	Hair coat code[c] at 30 degrees F		Hair coat code[c] at 10 degrees F		Hair coat code[c] at -10 degrees F	
	1	3	1	3	1	3
Beef cow wintering ration (hay @ .90 Mcal ME/lb. DM)						
Hide code[d]	Wind @ 1 mph					
1	1.19	1.19	1.29	1.68	1.58	2.07
2	1.19	1.19	1.29	1.55	1.41	1.92
3	1.19	1.19	1.29	1.45	1.39	1.79
	Wind @ 10 mph					
1	1.22	1.48	1.60	1.94	1.98	2.39
2	1.19	1.41	1.47	1.84	1.82	2.27
3	1.19	1.34	1.36	1.75	1.69	2.17
Typical calf wintering ration (.35 Mcal NE_g/lb. DM)						
	Wind @ 1 mph					
1	1.19	1.47	1.50	2.93	1.87	2.39
2	1.19	1.37	1.36	1.80	1.69	2.23
3	1.19	1.28	1.29	1.69	1.55	2.09
	Wind @ 10 mph					
1	1.41	1.69	1.85	2.20	2.29	2.72
2	1.30	1.61	1.71	2.10	2.12	2.59
3	1.21	1.54	1.60	2.01	2.98	2.48
Typical finishing ration (.62 Mcal NE_g/lb.DM)						
	Wind @ 1 mph					
1	1.19	1.19	1.33	1.76	1.69	2.21
2	1.19	1.19	1.29	1.63	1.51	2.05
3	1.19	1.19	1.29	1.51	1.39	1.92
	Wind @ 10 mph					
1	1.24	1.52	1.67	2.03	2.11	2.54
2	1.19	1.44	1.54	1.93	1.95	2.42
3	1.19	1.36	1.42	1.83	1.81	2.31

[a]Fox, D.G., C.J. Sniffen and J.D. O'Connor. Diagnosing cattle performance. IN: Proc. MacDonald College Nutrition Conference, Montreal, Quebec. Sept. 28, 1989.
[b]Values given are NE_m required for conditions given divided by no stress maintenance requirement (77 kcal/$BW_{kg}^{.75}$).
[c]1 is dry and clean, 2 is mud on lower body, 3 is wet and matted. [d]1 is thin (typical of Holstein and Zebu types), 2 is average, 3 is thick (hide thickness similar to Hereford types).

Table 2. Influence of milk production level, month of lactation and nursing calf forage intake on beef cow metabolizable energy (ME) requirements (Mcal/day)[a]								
	Month of lactation							
	1	2	3	4	5	6	7	8[b]
	1100 lb cow, 13 lb/day peak milk							
1984 NRC	20.3	20.3	20.3	20.3				
CNCPS; cow	21.4	21.9	22.7	21.2	20.6	20.1	19.8	19.9
cow+calf	23.4	25.1	26.4	27.4	28.2	29.7	31.5	34.9
	1320 lb cow, 24 lb/day peak milk							
1984 NRC	24.6	24.6	24.6	24.6				
CNCPS; cow	28.9	30.2	30.0	29.1	28.1	27.1	26.3	25.9
cow+calf	29.8	32.1	33.6	34.6	35.3	36.7	38.5	41.8

[a]Fox et al., 1988.
[b]The increase over the previous month includes increasing pregnancy requirements.

(Fox and Black, 1984; Fox et al., 1988; Rayburn and Fox, 1990) have been used to develop adjustments to NRC recommendations for use in typical ration balancing programs, including maintenance requirements, frame size, breed type, dry matter intake and feed energy values. For example, the NRC (1984, 1989) uses only one value to compute maintenance requirements for growing cattle and cows. However, maintenance requirements depend on the relationship between heat production and heat loss, which depends on metabolizable energy (ME) intake, animal insulation and environmental conditions. Table 1 shows adjustments for representative environmental conditions that were developed from our CNCPS model which can be used to adjust NRC (1984, 1989) maintenance requirements.

3. **Develop tables of nutrient requirements that are more mechanistic and cover a wide range in conditions.** NRC nutrient requirement recommendations historically have been highly aggregated for ease of use under generalized conditions where limited information is available. However, this approach limits their use for accurately computing requirements with wide variations in animal type. For example, beef cow requirements given by the NRC (1984) are for cows with either "moderate" or "high" milk production levels, and only for the first four months of lactation. Table 2 compares NRC recommendations for beef cows with those generated from our CNCPS (Fox et al., 1988), which are computed for each month of lactation, for cows across the range of potential milk production levels of beef cows, and for both the cow and calf pair (needed for forage allocation).

NRC (1984, 1989) deals with energy reserves by providing for weight gain allowance. However, it would be rare for a beef or dairy producer to know the weight gains of their cows; they monitor energy reserves by changes in condition score, which can be readily observed, and can be more accurately related to energy balance. Table 3 shows values generated from our CNCPS model that can be used to compute energy balance from condition score in cows (Fox et al., 1992).

4. **Estimate requirements for which no data is available.** We have a large number of cattle types utilized in the world for meat and milk production; for many of which no direct determinations of requirements have been made (Nicholson, 1990; Urbina, 1991). We developed and validated a system for determining the requirements of cattle varying widely in frame size

and sex (Fox et al., 1992; Tylutki et al., 1994). In this system, we first determined that all cattle have a similar body composition at the same degree of maturity, and the 1984 NRC medium frame size steer equation represents a growth curve for a particular body size based on a large body composition data base (Garrett, 1980). In a large validation study, with body composition data from cattle varying widely in body size, sex and ration type, this system accounted for 91 to 99% of the variation in energy retained and 74 to 96% of the protein retained (Tylutki et al., 1994). For example, table 4 (from Fox et al., 1993) shows the requirements computed for steers and heifers of widely varying body sizes and weights at 28% fat. Using this approach, we found that our CNCPS model accurately predicted the performance of Nellor bulls in Brazil if their frame score and feed carbohydrate fractions could be described (D. Lana, C. Boin and D. Fox; unpublished data).

5. **Predict requirements for nutrients and feed biological values that require a more detailed system of accounting.** The best example here is the prediction of degradable protein, rumen ammonia and peptide, and metabolizable protein and amino acid balances. The CNCPS is used to

Table 3. Energy reserves at different condition scores[a]

Score system	Condition score								
CNCPS	1	2	3	4	5	6	7	8	9
DAIRY	1	1+ to 2-	2	2+ to 3-	3	3+ to 4-	4	4+ to 5-	5
Body weight	Mcal per condition score								
1000	0	133	145	155	167	167	168	169	170
1100	0	147	159	171	184	184	186	187	188
1200	0	160	174	187	200	201	203	204	205
1300	0	174	188	203	217	219	220	221	222
1400	0	187	202	218	234	236	237	238	239
1500	0	200	216	233	251	253	254	255	256

[a]Fox et al., 1992. This table can be used to compute days for a condition score change as follows, assuming the following relationships:

Efficiency of use of ME for milk production (NE_l)	= .64
Efficiency of use of ME for energy reserves gain	= .75
Efficiency of use of reserves for milk prod. (NE_l)	= .82

1. Determine the energy reserves in the body weight at the condition score to be lost or gained. For example, a 1300 lb. cow in condition score 6 will contribute 219 Mcal of tissue energy as that condition score is "used up" or will require 219 Mcal of energy available at the tissue to regain that condition score.

2. If NE_l intake is below requirements, 1 Mcal of tissue energy will substitute for .82 Mcal of diet NE_l (or .82/.64 = 1.28 Mcal ME). Therefore days to change 1 CNCPS condition score = reserves energy in one condition score x .82 divided by NE_l deficiency. For example, if the ration fed a 1300 lb. cow provides 3 Mcal NE_l daily less than needed and the cow is CNCPS condition score 6, she will drop to a condition score 5 in (219 x .82)/3 equals 60 days.

3. If NE_l intake exceeds requirements, 1 Mcal of NE_l will provide (1/.64)x.75 = 1.17 Mcal tissue energy or 1 Mcal of ME will provide .75 Mcal tissue energy. In this example, the 1300 lb. cow at condition score 5 and consuming 3 Mcal NE_l in excess of requirements will move to a condition score 6 in 219/((3/.64)x.75) = 62 days.

predict the interactions of feed intake and ingredient carbohydrate and protein fraction composition, digestion and passage rates and their effect on microbial growth, feed carbohydrate and protein fractions escaping degradation and energy allowable weight gain or milk production and its composition to determine supplementation required (Chalupa et al., 1991; Chalupa and Sniffen, 1991; Chase, 1991).

Table 5 shows how predicted feed biological values can vary with animal and feed composition interactions in particular feeding situations with beef cattle. The top section shows TDN, NE_m and NE_g values from the 1984 Beef Cattle NRC. Shown next are biological values generated by the CNCPS for 2, 4, and 8%/h passage rates, the range typical for feeds at 1x to 4x level of intake. For rapidly growing cattle and high producing lactating beef cows, predicted intake can range from 2 to 4x and passage rates can range from 4 to 6%/h for the forages and 8%/h for the concentrates, depending on density, degree of hydration and processing and level of intake. The passage rates would be about half these values at 1x level of intake, typical for dry beef cows. Typical feedlot cattle passage rates and cows with low levels of milk production would be between these two extremes. The passage rate can also vary with feed eNDF value. Within each of these categories, feed TDN, NE_m, NE_g and metabolizable protein from microbial protein (MTP) are predicted, and at 8%/hr are predicted for both the high (6.5) and low (5.7) ruminal pH that can occur. The first observation is that percent of carbohydrate and protein escaping ruminal fermentation varies considerably depending on passage rate and type of feed and its effect on microbial protein production and undegraded feed protein. To maximize microbial protein production, it is very important to have the grain fermented in the rumen. Passage rate has little effect on escape protein in feeds (such as corn silage) with a high proportion of rapidly and slowly degraded protein. The adequacy of the tabular values for DIP depend on the level of intake of the cattle. Passage rate had the greatest effect on feed energy values for forages, because of their lower intestinal digestibility. Rumen pH had a dramatic effect on both forage energy value and MTP. These values reflect a 0% digestion rate for the available NDF at the low pH and approximately 40% less MTP yield from A and B1 carbohydrates.

Essential amino acid balances can be estimated within the structure of the CNCPS because the effects of the interactions of intake, digestion and passage rates on microbial yield, available undegraded feed protein and estimates of its amino acid composition can be predicted along with microbial, body tissue and milk amino acid composition. However, the development of more accurate feed composition and digestion rates, and more mechanistic approaches to predict utilization of absorbed amino acids will result in improved predictability of diet amino acid adequacy for cattle. Sources of first limiting essential amino acids are adjusted where practical to improve the amino acid profile. In preliminary studies, energetic efficiency appeared to improve as essential amino acid profiles approached that of requirements (Fox et al., 1995).

6. **As a tool for extending research results to varying farm conditions.** Responses from different treatments in experiments can often be duplicated in the field only if the conditions are similar to those under which the experiment was conducted, including feed intake and composition, animal type and production level, environment and animal management. We have been using our models to design experiments that will provide data for improving prediction of responses to critical variables and to provide model validation data. Then we use models in the field to predict possible outcomes rather than use the experimental results directly, thereby accounting for the variables unique to each farm. For example, Rayburn and Fox (1990) used a large database to refine and validate the model of Fox et al. (1988) for predicting the performance of Holstein steers. This refined model, which we call Cornell Cattle Systems 4 (CCS4), is then used on farm to evaluate rations and alternative feeding and management strategies. When Revalor implants became available, we conducted a series of experiments over logical conditions it would likely be used with Holstein steers to determine the animals biological response (energy and protein content of gain, maintenance requirement, dry matter intake, etc.). We then used the data to develop biologically correct adjustments for Revalor in our model and to validate the model predicted response. We now use the model on-farm to predict the performance and profitability of using Revalor under various conditions rather than the average experimental response.

Table 4. Net energy and absorbed protein requirements for gain of growing cattle varying in body size.

mature or 28% fat weight	Steer or herd replacement heifer equivalent weights					
1030 lb. NE_m, Mcal/day	500 4.51	600 5.17	700 5.80	800 6.41	900 7.00	1000 7.58
1170 lb. NE_m, Mcal/day	571 4.98	685 5.71	799 6.41	913 7.08	1027 7.73	1141 8.37
1320 lb. NE_m, Mcal/day	642 5.44	771 6.24	899 7.00	1028 7.74	1156 8.45	1285 9.15
1470 lb. NE_m, Mcal/day	714 5.89	857 6.75	1000 7.58	1143 8.38	1285 9.15	1428 9.90
28% fat weight	Feedlot heifer equivalent weights					
820 lb. NE_m, Mcal/day	400 4.21	481 4.37	561 4.91	641 5.43	721 5.93	801 6.42
940 lb. NE_m, Mcal/day	456 4.21	547 4.82	639 5.41	730 5.98	821 6.54	912 7.08
1060 lb. NE_m, Mcal/day	514 4.60	617 5.28	719 5.92	822 6.55	925 7.15	1028 7.74
1180 lb. NE_m, Mcal/day	572 4.98	686 5.71	800 6.41	915 7.09	1029 7.75	1143 8.38
Daily gain, lb.	NE_g requirements, Mcal/day					
1.00	1.37	1.57	1.76	1.95	2.13	2.31
1.50	2.14	2.45	2.75	3.04	3.32	3.60
2.00	2.93	3.36	3.77	4.17	4.56	4.93
2.50	3.75	4.30	4.82	5.33	5.82	6.30
3.00	4.58	5.25	5.89	6.51	7.11	7.70
3.50	5.42	6.21	6.97	7.71	8.42	9.11
Daily gain,lb.	Absorbed protein requirements for gain, g/d					
1.00	142	144	148	153	161	171
1.50	208	211	216	222	231	243
2.00	273	276	281	288	297	311
2.50	338	340	345	352	362	377
3.00	401	403	407	414	424	439
3.50	464	465	469	475	485	500

Table 5. The effect of animal and feed composition factors on feed biological values.

	Corn Silage	Brome Hay	Alfalfa Hay	Dry Corn grain	HiMoistCorn
	Tabular values (1984 Beef NRC)				
TDN(% of DM)	70	55	60	90	93
NE_m(Mcal/kg)	1.63	1.14	1.31	2.24	2.33
NE_g(Mcal/kg)	1.03	.58	.74	1.55	1.62
	CNCPS predicted @ passage rate of 2%/hr				
DIP(% of CP)	79	63	71	64	77
TDN(% of DM)	70	60	60	85	86
NE_m(Mcal/kg)	1.63	1.31	1.31	2.09	2.12
NE_g(Mcal/kg)	1.03	.74	.74	1.43	1.45
MTP(g/kg)	62	48	51	71	79
	CNCPS predicted @ passage rate of 4%/hr				
DIP(% of CP)	75	58	63	52	72
TDN(% of DM)	65	53	57	82	85
NE_m(Mcal/kg)	1.47	1.07	1.21	2.00	2.09
NE_g(Mcal/kg)	.88	.52	.64	1.35	1.43
MTP(g/kg)	55	36	46	61	74
	CNCPS pred. @ Passage rate of 8%/hr, pH 6.5				
DIP(% of CP)	69	51	54	39	65
TDN(% of DM)	60	47	54	79	83
NE_m(Mcal/kg)	1.31	.86	1.11	1.91	2.03
NE_g(Mcal/kg)	.74	.32	.55	1.27	1.37
MTP(g/kg)	46	30	41	48	66
	CNCPS pred. @ Passage rate of 8%/hr, pH 5.7				
TDN(% of DM)	52	36	49	78	82
NE_m(Mcal/kg)	1.04	.45	.93	1.88	2.00
NE_g(Mcal/kg)	.49	0	.39	1.24	1.35
MTP(g/kg)	21	10	20	27	38

7. **Direct on-farm use to evaluate feeding programs.** Given adequate feed composition values and knowledge of how to use input values, the CNCPS has been successfully used to predict ME, NE, and amino acid requirements and supply for a particular production setting. First, the animal, environmental and feed compositional factors must be described as accurately and completely as possible. However, because many of the factors (body size, environmental conditions, feed digestion rates, particle size, etc.) depend on field observation, the input factors must be adjusted in a logical way until the model predicts the performance that is being observed before alternatives can accurately be evaluated. This approach allows requirements to be computed for the specific animal, environmental, DMI and feed compositional conditions.

8. **To integrate animal, feed, and economic variables to select the most profitable feeding system and manage risk.** Our models for growing cattle have been used for many years first as a menu driven fortran program (Michigan Telplan programs 44 and 56; Fox and Black, 1977 and Black and Fox, 1977) then as a spreadsheet (Cornell Cattle Systems Series; Fox et al., 1994) to balance rations and predict days on feed, feed budgets, cost of gain and breakeven sale price. A spreadsheet for beef cows (Fox and Rasmussen, 1989) is used to identify the optimum combination of forages and beef cows on a particular farm and their impact on costs and returns. The CNCPS has been used as the "nutritional engine" in an expert system to identify dairy herd management weak links. It has been used to identify optimal management and feeding strategies in tropical settings with dual purpose cows (Nicholson, 1990 and Urbina, 1991).

CONCLUSIONS

Computer models will have to be used to improve our system of accounting to accurately formulate cattle feeding programs for continued reductions in resource use per unit of production. Adequate information must be available to accurately drive the models, however and the user must have an understanding of the underlying concepts to adjust them to the situation. Their use could be counterproductive in situations where information or user knowledge is limited; in these situations more aggregated systems will be less risky to use.

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