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A critique of the Cornell Net Carbohydrate and Protein System with emphasis on dairy cattle. 2. The post-rumen digestion model

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ABSTRACT

The Cornell Net Carbohydrate and Protein System (CNCPS) post-rumen digestion model calculates nutrient absorption in the small intestine from microbial cell, feed residue and endogenous secretion composition, but thereafter it only makes use of one class of nutrient, the absorbed amino acids (AA). This is because apparently digested protein, carbohydrate and fat are amalgamated in the calculation of total digested nutrients (TDN) as a measure of energy supply, which is then converted to digested energy (DE), metabolizable energy (ME) and net energy for lactation (NEL). At the maintenance level of feeding, this results in TDN values for feeds 0.5 to 2.5% below those listed in NRC (1988). ME values predicted at a typical production feeding level (L = 4) are about 6% below the listed maintenance level values, when a reduction of only about 5% would be predicted. The model makes no direct use of NRC (1988) tabulated values for the TDN, DE, ME or NEL of feeds. A sensitivity test of the supply model revealed that variations of ±10% in many of the input parameters were without significant effect upon the nutrient supply measured as TDN or metabolizable protein (MP) supply. Variations in dietary crude protein (CP) concentration affected rumen N and peptide supply, and MP supply from undegraded intake protein (UIP). Plasma urea N and milk urea N varied ±20% because of a multiplier effect within the model, twice the imposed CP% variation. Variations in neutral detergent fibre concentration (NDF%) affected effective NDF (eNDF) and microbial protein synthesis. Variations in the rate of degradation of cell walls (NDF) caused a mean change of ±7.7% in microbial efficiency, whereas variations in the degradation rates for the A and B1 carbohydrate (CHO) fractions were without effect on microbial efficiency. Variations in starch content (B1 fraction of CHO) quantitatively affected microbial production, but this was offset by a consequential reduction in the size of the A fraction (sugars and soluble CHO) of CHO, if all other

parameters were held constant. Variations in the fat content of the diet produced significant effects upon predicted TDN and ME values, because of the high gross energy of fat and the multiplier (2.25) used on fat percentage in the calculation of TDN values. Published tests of the CNCPS claim that it can predict non-ammonia nitrogen (NAN) outflows from the rumen of dairy cattle adequately. There are weaknesses in the statistical analysis of the NAN data, particularly the pooling of data from growing cattle with that from dairy cows. Later work has shown that NAN supply in the CNCPS is over predicted with high undegraded protein diets, since any shortage of rumen degraded protein does not reduce microbial protein synthesis.

KEY WORDS: CNCPS, dairy cows, lactation, rumen, metabolism, energy, protein, amino acids, supply

INTRODUCTION

A preceding paper (Alderman et al., 2001a) reviewed the rumen sub-model of the CNCPS. This paper deals with the post-rumen digestion sub-model and uses the same terminology and symbols as used in the original set of papers defining the model (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992; O'Connor et al., 1993)

PREDICTION OF NUTRIENT SUPPLY TO THE SMALL INTESTINE

Digestion coefficients

Fixed digestion coefficients for each feed nutrient fraction and the true protein, nucleic acid, carbohydrate and fat components of the rumen bacteria are used in the model, as shown in Table 1, where they are compared with the AFRC (1992) and INRA (1988) coefficients.

TABLE 1

Digestibilities of undegraded feed fractions and bacterial components

Model	Protein fractions				Fat	CHO		Bacterial fractions			
	B1	B2	B3	C		B1	B2	BTP	NA	CHO	Fat
CNCPS	1.0	1.0	0.8	0	0.95	v	0.20	1.0	1.0	0.95	0.95
AFRC		0.5 - 0.9			ns	ns	ns	0.85	ns	ns	ns
INRA		0.25 - 0.9			ns	0.80	ns	ns	ns	ns	ns

BTP – bacterial true protein
NA – nucleic acids
ns – not stated
v – variable according to source and processing

Where values have been stated in other models for feed and microbial protein, the CNCPS values are higher. Constant values for the digestibility of bacterial fat and carbohydrate are adopted, whilst feed starch digestibility once it has escaped from the rumen is known to vary with type of feed and the method of processing (Owen et al., 1986).

Estimation of faecal losses

Ruminant faeces normally contain little of the feed's cell contents, with the exception of starch and heat damaged proteins. In the UK MP system (AFRC, 1993), any undigested feed protein appearing in faeces is calculated as 6.25 times acid detergent insoluble N (ADIN) content. Undigested cell walls are also found, together with undigested microbial matter and excreted endogenous substances. Within CNCPS, undigested feed proteins fractions B3 and C, carbohydrate starch (A2), available (B1) and unavailable fibre (B2) are calculated as (1- RD) times the amount of the nutrient fraction present, multiplied by the appropriate intestinal digestibility, where RD is the proportion of the fraction degraded whilst in the rumen. Undigested microbial nutrient fractions (bacterial cell wall protein, bacterial protein, carbohydrate and fat are calculated using 1 minus the assigned digestibilities (Table 1) for these fractions, and summed.

The amounts of protein, fat and ash in endogenous matter (salts of fatty acids, bile salts, sloughed animal cells, mucous and keratinised tissue) are calculated according to Sniffen et al. (1992) by equations given by Lucas et al. (1961), driven by dietary protein intake (DIETPROT). But the associated footnote refers to FD, feed DM consumed, which does not appear in the equations of Lucas et al. (1961). However, in CNCPS v.3.0, the parameter DIETPROT has been replaced with indigestible (undigested) dry matter (IDM), as suggested in NRC (1996), p.125, also attributed to Lucas et al. (1961). The total faecal dry matter (IDM) is then calculated by summing the undigested feed, microbial and endogenous dry matter fractions. Unfortunately, endogenous faecal protein (FEENGP) is a component of faecal protein, which is included in the calculation of IDM. The equation for IDM proposed by NRC (1996) is therefore infeasible. However, CNCPS v.3.0, omits the term FEENGP, from the equation for IDM and divides the RHS of the equation by 0.91, thus correcting for 0.09 IDM from FEENGP:

$$IDM = (FEPROT + FECHO + FEFAT + FEASH)/0.91 \quad (1)$$

Estimates of energy and protein supply

Estimation of total digestible nutrients. In the CNCPS, TDN as g/d are calculated from the dietary inputs of protein, carbohydrate and fat, less the amounts of these nutrients calculated to be present in the faeces, plus microbial OM and

endogenous substances. When TDN is expressed per kg dry matter intake, the TDN supply, the result is a production level TDN value, (aTDN%), which as stated by NRC (1988), will be 4% lower per unit increase in feeding level above the maintenance feeding level, than the maintenance (basal) TDN (bTDN%) values listed in the tables of feed composition in NRC (1988).

Estimation of digestible and metabolizable energy intakes. In the CNCPS, energy supply, expressed as DE and ME, is calculated from the supply of aTDN (not bTDN), as g/d. This value is applicable to the level of feeding of the diet in question, and should not be compared with dietary TDN, DE or ME intakes calculated from feed bTDN, DE and ME values listed in Table 7.1 of NRC (1988). This has important consequences when these estimates of energy inputs are matched with NRC (1988) ME requirements for dairy cattle.

DE values as Mcal/kg DM are then calculated from TDN using the NRC (1988) conversion factor of 4.409 Mcal/kg TDN (18.45 MJ/kg), which is accurate since the gross energy values of nutrients are unaffected by level of feeding effects. ME values are calculated by using DE/ME = 0.82, which is only appropriate at the maintenance feeding level for dairy cattle. The relevant DE to ME conversion equation of Moe et al. (1972) quoted in NRC (1988):

$$\text{ME (Mcal/kg DM)} = -0.45 + 1.01\text{DE (Mcal/kg DM)} \quad (2)$$

yields values for DE/ME of 0.84-0.86 for the working range of dairy cow diet ME values. However, it incorporates no level of feeding effect upon digestibility and methane production at high feeding levels, as later suggested by Moe and Tyrell (1976) and Van Es (1978). The adoption of a factor of 0.82 for DE/ME is not supported by more recent calorimetric work (Beever et al., 1989; Yan et al., 1997), where mean values nearer 0.86 for ME/DE have been measured for lactating dairy cows, in agreement with Moe et al. (1972).

Net energy values for lactation are then calculated in the various versions of the CNCPS using a fixed efficiency factor (k_l), i.e.:

$$\text{NEL (Mcal/kg DM)} = 0.65\text{ME (Mcal/kg DM)} \quad (3a)$$

or

$$\text{NEL (Mcal/kg DM)} = 0.644\text{ME (Mcal/kg DM)} \quad (3b)$$

Equation (3b) is that of Moe et al. (1972), but neither equation is as NRC (1988) which has:

$$\text{NEL (Mcal/kg DM)} = 0.703\text{ME (Mcal/kg DM)} - 0.19 \quad (4)$$

In equation (4), ME concentration of the diet affects lactation efficiency (k_l = NEL/ME), which varies from 0.61 for ME = 2 Mcal/kg DM (8.4 MJ/kg DM) to 0.64 for

ME = 3 Mcal/kg DM (12.6 MJ/kg DM). Thus the CNCPS predicts slightly higher (+3%) NEL from ME than NRC (1988).

Protein supply. MP supply is calculated from the estimates of microbial protein production from degraded carbohydrate and the feed protein fractions that have escaped from the rumen, in a similar manner to other published ruminant protein models (ARC, 1980, 1984; Madsen, 1985; NRC, 1985; INRA, 1988; SCA, 1990; AFRC, 1992; Tamminga et al., 1994). None of the current protein supply models, except the CNCPS, consider the activities of rumen protozoa, although their assumed rumen microbial composition data includes protozoa. All systems estimate the amount of protein degraded in the rumen, but most use fixed outflow rates in their calculation, except the CNCPS and AFRC (1992) which calculate outflow rates based on the level of feeding.

The CNCPS estimates the digestible microbial true protein in microbial crude protein (DMTP/MCP) by a different route to other models. In particular, the bacterial cell walls are assumed to be indigestible and the estimate for the nucleic acid content of rumen bacteria (Purser and Buechler, 1966) is lower than that adopted by AFRC (1992). The end result (0.60) is little different to other models, which have DMTP/MCP = 0.64, except for SCA (1990), which adopted 0.56.

Estimates of undegraded feed protein are predicted from the ADIN and lignin determinations on the component feeds of the diet as specified by Van Soest (1982). In comparison, the dacron bag *in situ* technique of Ørskov and Mehrez (1977) gives quantitative estimates of the amount of undegraded protein.

AMINO ACID MODEL

The amino acid sub-model of the CNCPS predicts the supply of and the requirement for absorbed amino acids. Its basis is the prediction of MP supply as described in Fox et al. (1992) and animal MP requirement as specified by NRC (1985).

Amino acid composition of rumen bacteria

The AA composition of rumen bacteria adopted in the CNCPS is based on the estimates of Mantysaari et al. (1989) for the cell contents of the rumen bacteria, whilst the AA content of bacterial cell walls are as measured by Hoogenraad et al. (1970). As bacterial cell walls are assumed to be indigestible, this is of little importance. Table 1 of O'Connor et al. (1993) gives the AA values from these sources and compares the cell content AA data with the values for whole rumen bacteria of Clark et al. (1992), showing good agreement, except for histidine and

arginine, which are lower in bacterial cell walls. Rulquin et al. (1993) gave a full microbial AA profile from a review of 66 data sets by Le Henaff (1991), with a individual coefficients of variation of 7-20%. Mean values for five essential AA listed are compared in Table 2 with those of Storm and Ørskov (1983) and those adopted in the CNCPS.

These values are in generally good agreement, particularly for methionine and lysine, with the exception of the valine figure of Storm and Ørskov (1983). Within CNCPS, the total supply of each AA is calculated from the predicted supply of rumen bacterial true protein and bacterial cell wall.

TABLE 2

Essential amino acid content of rumen bacterial DM, g/kg

Amino acid	CNCPS (1992)	Le Henaff (1991)	Storm and Ørskov (1983)
Leucine	75	77 ± 5	76
Isoleucine	59	59 ± 6	56
Valine	62	62 ± 6	52
Lysine	82	80 ± 10	84
Methionine	27	25 ± 6	26

Digestibility of amino acids in rumen bacteria

Rumen microbial cell contents are assumed to be 0.95 to 1.0 digestible, but that the AA in the cell walls are not released by proteolytic enzymes in the abomasum and small intestine, and may be of limited value to the animal, so the AA in bacterial cell walls are assumed to be completely indigestible in the intestines.

Amino acid composition of undegraded feed protein

Only the AA composition of the insoluble feed protein fractions B2 and B3 are required, since the soluble protein fractions A and B1 do not reach the intestine in any significant amount, whilst protein fraction C by definition is indigestible. The AA profile of insoluble protein B2 and B3 differs from that of the total feed according to Mantysaari et al. (1989), but there is other evidence that no significant differences exist (Hvelplund, 1987).

Digestibility of undegraded feed amino acids

The ruminally escaped feed protein fractions B1, B2 and B3 are assigned true digestibilities of 1.0, 1.0 and 0.80, whilst the C fraction by definition has a digesti-

bility of zero. These values are applied uniformly to the AA fractions digested in the intestines. These assumptions can be compared with the value of 0.70 for all undegraded true protein adopted by ARC (1980). AFRC (1992) adopted an equation suggested by Webster et al. (1984) to predict digestible undegraded protein (DUDP) from undegraded protein (UDP), using the ADIN content of feeds:

$$DUDP = 0.9(UDP - 6.25ADIN) \quad (5)$$

where DUDP, UDP and ADIN are all in g/kg DM. This gives a range of digestibilities of UDP varying from 0.5 to 0.9 for the normal range of ruminant feed composition. The digestible AA supply for each feed component is then calculated and the sum of these individual calculations for each AA yield the total AA supply to the animal.

SENSITIVITY TESTING OF CNCPS v.3.0 SUPPLY MODEL

Some sensitivity analyses of the CNCPS when applied to dairy cattle have already been reported (ADAS, 1997). It was found in particular that predicted ME supply was very sensitive to the level of fat in the diet. Given the high energy value of fat (39.3 MJ/kg DM; ARC, 1980), and given that in the CNCPS 0.95 of fat is presumed to escape from the rumen unchanged, and is assigned a high (0.85) intestinal digestibility, this is not surprising. The first assumption of fat escaping unchanged from the rumen has been challenged by Dijkstra and France (1996), as discussed in Alderman et al. (2001a). Further sensitivity testing of the 1994 issue of the CNCPS v.3.0 of the model has been undertaken, with the following results.

Procedure. A standard CNCPS run was devised using a 600 kg liveweight dairy cow in early lactation, giving 35 kg milk/d, at 3.8% milk fat and 3.4% milk protein, and fed a total mixed ration comprising grass silage, wheat, soyabean meal, and dried sugar beet pulp.

Feed input parameters studied

1. Crude protein, soluble protein, non-protein nitrogen (NPN)
2. Neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP)
3. NDF, starch, fat, eNDF
4. Degradation rates for carbohydrate fractions A (Kd_4), B1 (Kd_5), and B2 (Kd_6)
5. Degradation rates for protein fractions B1 (Kd_1), B2 (Kd_2), and B3 (Kd_3)
6. Three animal parameters: liveweight, milk fat and protein

Model output parameters studied

1. ME and MP supply and requirements
2. Rumen N and peptide supply, predicted rumen pH
3. Predicted microbial protein yield from A, B1, B2 CHO fractions and total CHO pool
4. MP supplied from rumen bacteria and UIP
5. Predicted plasma urea N (PUN) and milk urea N (MUN)

The output from the CNCPS for the defined dairy cow, using the standard feed input values, is shown in Table 3.

TABLE 3

Standard CNCPS output using the dairy cow and diet as defined

Parameter	Requirement	Supply
ME, MJ/d	236	240
MP, g/d	2469	2477
eNDF, kg/d	4.1	4.1
Diet crude protein, %DM		19.8
MP from bacteria, g/d		1.654
MP from UIP, g/d		824
Total NSC, %DM		38

The feed parameters in the model were then increased or decreased by 10% and the magnitude of the changes induced in the output parameters of this version of the model was recorded. A selection of the more significant results expressed as means (plus or minus) are shown in Table 4.

Results

1. NDF% in DM affected eNDF% and MCP from CHO pools A, B1 and B2, but not total CHO. The latter effect is because total CHO is the sum of structural carbohydrate (SC) and non-structural carbohydrate (NSC), calculated as 100 - (CP% + EE% + Ash%), none of which was varied.
2. Variations in crude protein % in DM affected rumen ammonia N (RAN) and peptide supply, MP supply from UIP, PUN and MUN. Increases in CP% in diet DM, by definition, decrease the total CHO fraction. If NDF and starch are held constant, as here, then the A CHO fraction (calculated by difference from total CHO) will be reduced, thus lowering the microbial yield, even if more degradable N is supplied. In the CNCPS, MCP yield is not limited by the degradable N

TABLE 4

CNCPS sensitivity test results

Parameters changed ±10%	Mean	All values as mean percent change															
		Requirement		Supply		Rumen N	Rumen peptide	Effective NDF	Rumen pH	MCP from pool				MP from bacteria	MP from UIP	PUN	MUN
		ME	MP	ME	MP					A	B1	B2	Total				
NDF, %DM	34.5	0.27	1.01	2.09	1.55	0.19	0.44	9.76	1.35	6.28	6.31	13.10	2.17	2.21	0.91	2.78	3.33
Lignin, %NDF	5	-	0.20	0.44	0.22	-	-	-	-	-	-	1.55	0.35	-		-	3.33
CP, % DM	19.8	0.98	0.10	0.26	1.29	11.94	9.73	-	-	3.55	4.30	1.30	3.16	3.02	10.01	19.44	2.00
Soluble P, %CP	55	0.18	-	0.09	3.59	2.80	4.42	-	-	0.26	0.28	-	0.20	0.21	10.38	-	3.33
NPN, % Sol. P	68	0.09	0.02	0.09	0.44	0.19	9.96	-	-	0.61	0.62	-	0.48	0.48	0.30	-	-
NDIP,%	17	0.09	0.04	0.09	1.03	0.93	2.43	-	-	0.71	0.69	1.25	0.26	0.27	2.61	-	3.33
ADIP,%	4	0.09	0.04	0.17	0.46	-	0.22	-	-	-	-	-	-	-	1.40	-	-
Starch ,%NSC	25.3	-	-	0.09	0.28	-	-	-	-	3.38	9.99	-	0.43	0.42	-	-	-
Fat, %DM	4.1	0.09	-	0.78	0.52	-	-	-	-	1.02	0.97	-	0.78	0.79	-	-	3.33
Ash, %DM	7.2	0.09	0.24	1.13	0.93	-	0.22	-	-	1.79	1.80	-	1.38	1.39	-	-	3.33
eNDF, %NDF	59	0.27	0.04	0.17	1.35	0.19	0.66	9.76	1.35	2.14	2.15	2.20	2.13	2.09	0.91	-	3.33
CHO-A, %/h	315	-	-	0.09	0.14	-	-	-	-	0.35	-	-	0.22	0.21	-	-	-
CHO-B1, %/h	38.8	-	-	0.09	0.28	-	-	-	-	0.02	2.57	-	0.41	0.39	-	-	-
CHO-B2, %/h	6.16	0.09	0.47	0.96	1.17	-	-	-	-	-	-	7.70	1.75	1.72	-	-	3.33
Protein-B1, %/h	280	-	-	-	0.06	-	-	-	-	-	-	-	-	-	0.12	-	-
Protein-B2, %/h	8	0.09	-	0.09	1.03	0.75	1.77	-	-	0.11	0.14	-	0.09	0.09	3.28	-	-
Protein-B3, %/h	0.69	-	-	0.09	0.18	0.19	1.55	-	-	0.02	-	-	0.01	0.03	0.55	-	-
Weight, kg	600	2.22	-	0.52	0.24	0.65	1.55	-	-	0.17	0.76	2.45	0.78	0.79	2.31	-	3.33
Milk fat, %	3.8	2.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milk protein, %	3.4	0.35	7.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-

supply for the NSC bacteria. Thus if CP increases, CHO fraction A1 decreases, using less RAN, with the result that RAN, PUN and MUN show a multiplier effect with values reaching a mean change of 20% for a 10% change in CP intake.

3. The effect of varying dietary NPN content on rumen peptide supply is straightforwardly a difference effect within the total CP supply.
4. Alterations in starch content quantitatively affect the microbial production from the B1 starch pool, as was to be expected, but the reduced effect on the A CHO pool is less easy to explain, since A will be reduced in the opposite direction to variations in starch. It appears to depend upon the pool size, since the amount as g/d may have been the same as the change in starch, but the results are expressed as percent of the total pools, which may differ in size.
5. The effect of varying eNDF as % of NDF on eNDF supply is quite straightforward, but the 2% mean change in microbial efficiency conceals a depression of 4% when eNDF was reduced by 10% and a nil effect when eNDF was raised. This is because the diet DM eNDF level was 59% of 34.5% = 20.4%, close to the critical limit for maximum microbial efficiency (YG). It also results in the prediction of a slightly reduced rumen pH value of 6.23 compared to the norm of 6.46. The net effects of both changes are to reduce microbial efficiency for a reduction in eNDF below 20%.
6. Changes in the rate of CHO degradation for the B2 CHO pool, specified as 6.16% /h (0.062 /h) caused a mean change of 7.7% in microbial efficiency, whereas the A1 and B1 fractions are without noticeable effect. The explanation can be seen in Figure 1 of Alderman et al. (2001a), which shows the curve for microbial efficiency (Y) is rising sharply for $Kd_6 = 0.05$ for fraction B2, whereas for $Kd_5 = 0.39$ (38.8%) for fraction B1 and 3.15 (315%) for fraction A, the curve has a very flat response to changes in Kd values.

Many changes had little or no effect on the model outputs, which may in some cases be considered surprising. Thus changing the rate of degradation of CHO fraction A (Kd_4) had no effect upon the pool size of the A fraction. The importance of dietary CP and NDF levels to the CNCPS is quite clear, although changes of ±10% may be smaller than sometimes occur in practice.

ACCURACY OF PREDICTION OF NUTRIENT SUPPLY TO THE DAIRY COW

The various components of the CNCPS supply model provide estimates of the absorbed energy, protein, fat and carbohydrate, both structural and non structural, even though the original version of the model did not predict the VFA supply from fermented carbohydrate. It is therefore possible to test the model against experimental data from dairy cows in calorimeters for energy balance and digestion trials for nutrient balances. Unfortunately, most of the published tests of the model have

focussed on dry matter intake, milk yield assuming zero energy balance, and NAN supply and amino acid balance. This leaves the critical question of energy balance largely untested, which, given the dimensions of negative body energy balances (c. 50 MJ/d) in early lactation in high genetic merit (HGM) dairy cows (Beever et al., 2001), requires urgent attention to check the accuracy of the overall energy accounting of models such as the CNCPS.

Prediction of TDN, DE and ME values of feeds

The sensitivity of predicted individual feed TDN, DE and ME values to changes in the rates of degradation of the CHO fractions has also been examined, as the latter, together with the solid outflow rate (Kp) adopted, define the amount of CHO degraded in the rumen (RDCHO). The rate of degradation assigned to the cell wall fraction B2 is particularly important, since undegraded cell walls are not digested lower down the digestive tract, unlike starch and sugar. Using all the relevant equations, the TDN and ME values of individual feeds were calculated. Peptides were assumed to be non-limiting on the microbial efficiency of the NSC bacteria fermenting the A and B1 carbohydrate fractions, i.e. Y2 and Y3 microbial efficiencies were increased by 18%.

The effects upon predicted TDN and ME value of using the feed composition, minimum and maximum Kd values listed in Sniffen et al. (1992) Tables 1-7, and varying feeding level and predicted outflow rates, are given in Table 5. These predicted values are compared with the NRC (1988) and AFRC (1993) listed measured maintenance plane *in vivo* values for the selected feeds.

TABLE 5

Comparison of predicted and tabulated TDN and ME values for individual feeds

Feed name	TDN values, g/kg DM					ME values, MJ/kg DM					
	A	B	C	D	NRC	A	B	C	D	NRC	AFRC
Maize grain	823	832	830	784	880	12.4	12.6	12.6	11.9	14.5	13.8
Lucerne hay	519	541	541	505	580	7.8	8.2	8.2	7.6	8.9	8.5
Maize silage	747	756	755	691	700	11.3	11.4	11.4	10.5	11.2	11.3
Soyabean meal	814	829	828	804	840	12.3	12.5	12.5	12.2	13.8	13.3
Rapeseed meal	734	754	753	720	690	11.1	11.4	11.4	10.9	12.1	12.0
Fish meal	867	867	867	867	770	13.2	13.1	13.1	13.1	12.5	14.2
Maize gluten feed	793	806	805	744	830	12.0	12.2	12.2	11.2	13.6	12.9
Means	757	769	768	731	756	11.4	11.6	11.6	11.1	12.4	12.3

A – Minimum Kd values used at feeding level L = 1 (maintenance)
B – Minimum Kd values, except Kd_6 at maximum, used at feeding level L = 1 (maintenance)
C – Maximum Kd values used at feeding level L = 1 (maintenance)
D – Maximum Kd values used at feeding level L = 4

Predicted TDN values at the maintenance feeding level (L = 1) are on average 1.6 % above the NRC (1988) tabulated values when all Kd values are set at the maxima listed by Sniffen et al. (1992), (columns C v. NRC in Table 5). The predicted ME values at L = 1, average 6.5% below those tabulated in NRC (1988), and 5.7% below those in AFRC (1993), both sets of data being derived from digestibility measurements made with sheep or cattle fed at the maintenance level of feeding. The effect of setting feed SC degradability values (Kd_6) at their minimum values, whilst all others were set at maximum values, was to reduce both predicted TDN and ME values close to those when all Kd values were set at their minima, (columns A v. B in Table 5). This reinforces the conclusion of the sensitivity testing shown in Table 4, that CNCPS predictions on dairy cow diets are sensitive to the feed degradability Kd_6 values for cell walls (SC) adopted for use in the model.

The low predicted ME values in column C (L = 1) of Table 5 can be attributed in part to the ME/DE ratio of 0.82 used when converting DE values to ME values. Beever et al. (1989) suggested a mean value of 0.86 would be more appropriate, which eliminates the difference with AFRC (1993) ME values, but the predicted ME values are still 2.0% below NRC (1988) table values.

The effect of increasing the feeding level of a 60% forage diet to feeding level L = 4 times maintenance (equivalent to milk yields of 35-40 kg/d) increases the solid outflow rates of forages and concentrates from 0.022 and 0.028 /h to 0.055 and 0.075 /h, respectively. The predicted TDN values are reduced by 4.8%, 1.6% per unit increase in L, which can be compared with the reduction of about 4% per unit increase in L for digestibility values (DE and TDN) suggested by Moe and Tyrrell (1976). ME values are reduced by 4.3% below NRC (1988) values for L = 1 (columns C v. D). ARC (1980) would predict a reduction of 5.4%, whilst Moe and Tyrrell (1976), 2% per unit L for ME values, would give 6% for L = 4. Thus at a typical practical feeding level (L = 4), the CNCPS gives ME values averaging 1% below predicted AFRC (1993) production ME values for L = 4, because two errors are cancelling out, i.e. the low predicted ME values at L = 1 are reduced by a smaller amount when L = 4. This is due to the much smaller effect of feeding level upon outflow rates in the model compared to those of AFRC (1992; 1993), identified in Alderman et al. (2001a). Mansbridge et al. (1999) carried out a test of the CNCPS v.3.0 with feed inputs measured and sampled for analysis from 10 dairy farms on two occasions. They found that dietary ME concentrations reported by the CNCPS were on average 9% below the dietary maintenance level ME values assigned to the diets, where forage ME values were obtained using existing assessment methods and AFRC (1993) table values were used for concentrates.

The predicted ME values, calculated at the actual feeding level of the cow in question, are then converted to NEL units as 0.65ME (Sniffen et al., 1992), which

is not as NRC (1988), which on page 9 gives an equation for the prediction of NEL values at L = 3 from TDN values at maintenance that has an 8% reduction in TDN value built in:

$$\text{NEL (L = 3) (Mcal/kg DM)} = 0.0245\text{TDN\% (L = 1)} - 0.12 \quad (6)$$

A comparison of the CNCPS method of calculating NEL values and the NRC (1988) recommended method are given in Table 6, which shows them to be within ± 2% of NRC (1988) values for a feeding level of three times maintenance (L = 3).

TABLE 6

Net energy for lactation values according to CNCPS v.3.0 and NRC (1988)

CNCPS v.3.0				NRC (1988)	
TDN% (1)	TDN% (3)	ME, Mcal (3)	NEL, Mcal (3)	TDN%DM (3)	NEL, Mcal (3)
50	47.6	1.72	1.12	46.0	1.11
60	57.1	2.07	1.34	55.2	1.35
70	66.6	2.41	1.57	64.4	1.60
80	76.2	2.75	1.79	73.6	1.84
90	85.7	3.10	2.01	82.8	2.09
Means	66.6	2.41	1.57	64.4	1.60

(1) etc. indicates level of feeding as multiple of maintenance

Although the energy requirements given by Fox et al. (1992) are based on the NEL unit, CNCPS v.3.0 uses ME as the unit for both supply and requirements, only using NEL when reporting diet energy concentrations. The error introduced by matching predicted production level ME supply to ME requirements specified to be used with maintenance level feed ME values therefore gives predicted performance levels well below those expected from the NRC (1988) energy standards for dairy cows.

Prediction of NAN flows

A number of papers, including the original series, have been published which give measured NAN flow in dairy and growing cattle, together with sufficient supporting data about the composition of feeds, intakes and production levels, to run the CNCPS. Russell et al. (1992) featured a comparison of predicted and observed bacterial N flow in their Figure 3, using published data from a number of sources, and combining data for growing cattle with lactating dairy cattle. They quote a regression with a slope of 0.94, an intercept of -12 g N/d, and an r^2 value of 0.88. However, their Figure 3 shows the data are clustered in two sets,

the growing cattle around 100 g N/d and dairy cattle at 300 g N/d, giving a misleadingly high r^2 value. Regressions using the two individual data sets might lead to different conclusions.

The same clustering of data sets for growing and lactating cattle can be seen in the duodenal N and NAN flow regression analyses of O'Connor et al. (1993). They also reported an extended evaluation of the CNCPS amino acid model when used for dairy cows. Twelve dairy cow and eight non-lactating cattle studies were collated in which duodenal flows were measured. When the two data sets were pooled, overall the CNCPS showed a good correlation between predicted and actual duodenal flows of N, bacterial N, total NAN, dietary NAN, and methionine, histidine, lysine, phenylalanine, threonine, isoleucine, leucine and valine, with r^2 values of 0.76-0.95. However, as with the earlier published test (Russell et al., 1992), the non-lactating cattle data are clustered at low levels of duodenal N and NAN flow, leading to artificially high correlations. Separate regressions for the two groups of cattle would be likely to give less good regressions and larger intercepts. Even so, there was a tendency to under-predict actual values at high duodenal flow levels and over predict at low flow levels. This observation can be explained by the usually higher fractional passage rate at higher feeding levels and the absence of the effect of passage rate upon microbial growth efficiency in the CNCPS.

DEVELOPMENTS IN THE POST-RUMEN MODEL SINCE 1992

Several changes have been made in the CPM Dairy version of the CNCPS in the procedures for calculating TDN, DE, ME and NEL values of diets, according to the associated Help file and a listing of equations in the model made available to the authors. Taken together, these have the effect of raising predicted diet ME values considerably from the levels recorded by the 3.0 version of the CNCPS. NEL values are not now used for expressing energy requirements, but dietary NEL concentrations are calculated and quoted for the benefit of those used to working with that energy parameter. ME is the preferred unit used in the CNCPS for expressing both energy supply and requirement of dairy cows, particularly since adopting the simplifying assumption of a constant efficiency of ME utilization for milk synthesis.

Modification of the factor for oil/fat in the calculation of TDN%

The CPM Dairy version of the CNCPS factor for fat has been revised upwards from 2.25 as originally defined to a value of 2.70, relying on the work of Andrews et al. (1991) and Weiss et al. (1992). Weiss et al. (1992) proposed a theoretically

based model for the prediction of the TDN values of forages and concentrates, not incorporated in the original series of papers describing the CNCPS. Their findings appear to have been adopted subsequently in versions 3.0 and 3.1 of the CNCPS. The original factor of 2.25 for fat was based on the ratio of the GE of carbohydrate (17.5 MJ/kg) and fat (39.3 MJ/kg). The higher factor of 2.7 was thought to reflect physiological differences in fat energy metabolism, and give more realistic ME and NE values for fats and fat containing feeds, but has small impact on the TDN value of basal forages low in fat. However, this adjustment confounds the digestible energy of a feed with its subsequent efficiency of utilization after digestion. For the set of feeds listed in Table 5 the effect of changing this coefficient for fat is to give a mean increase in TDN of only 0.8%, varying from 0-1.3%. Calculated DE, ME and NEL values would be similarly raised by this small adjustment. For pure fats, the increase reaches 20%, but this will normally only affect about 5% of the dairy cow diet.

The calculation of diet DE values from TDN is carried out in the CNCPS post-rumen model by using the conversion given by NRC (1988):

$$DE\ (Mcal/kg\ DM) = 0.04409TDN \qquad (7)$$

implying a mean energy value of 18.44 MJ/kg DM for digested nutrients. However, the model calculates internally the amounts digested of each of the individual nutrients (protein, fat, starch and sugars), all of which can be assigned well established mean energy values of 23.6, 39.3, 17.5 and 17.5 MJ/kg DM (ARC, 1980). It is therefore possible to calculate DE values directly and more accurately from digested nutrients, not *via* TDN. The effect is to raise the mean DE values for the feeds listed in Table 5 by an average of 0.6 MJ/kg DM or about 5%. This increase conceals a reduction of about 0.4 MJ/kg DM in the ME value of corn and maize silage, because their high starch contents are valued at only 17.5 MJ/kg DM, whereas soyabean and rapeseed increase in ME value by about 0.5 MJ/kg DM, because of their high protein contents, valued at 23.6 MJ/kg DM. On theoretical grounds, the calculation of TDN as a route to DE values should be abandoned, as the method introduces a distortion in the predicted DE and ME values of feeds produced by the CNCPS. However, the effect of this method of calculating DE in typical dairy cattle diets is likely to be small, since diet formulation constraints hold the variation of protein, starch and sugar within fairly narrow limits. Fat (unless protected) will normally not exceed 6% of diet dry matter.

Modification of the ME to DE ratio

The CNCPS uses a DE/ME ratio of 0.82, which seems too low because values for DE/ME of 0.86 to 0.88 have reported in calorimetric studies using typical dairy

cow diets. CPM Dairy has retained this constant value of 0.82 for diets at the maintenance level of feeding, but for lactation it is replaced with the un-referenced function:

$$ME\ (Mcal/kg\ DM) = 0.96DE\ (Mcal/kg\ DM) - 0.27 \quad (8)$$

which is not the same as that given for this conversion by NRC (1988) which gives:

$$ME\ (Mcal/kg\ DM) = 1.01DE\ (Mcal/kg\ DM) - 0.45 \quad (9)$$

Equation (8) generates ME/DE ratios of 0.85-0.88 as TDN varies 55-75% of DM, DE varies 2.4-3.25 Mcal/kg DM (10.2 -13.6 MJ/kg DM) and ME varies 2.1-2.85 Mcal/kg DM (8.6-1.9 MJ/kg DM). Thus for typical dairy cow diets fed at 3 times maintenance, ME/DE is 0.87-0.88, giving a 7% increase in predicted diet ME value. Equation (9) gives a range for ME/DE of 0.82-0.87, but for typical dairy cow diets is 0.01 lower than equation (8).

If the 1% increase in predicted TDN value is added in, an 8% increase in predicted ME value results. This mean increase has been confirmed exactly by the authors in parallel runs of 18 dairy cow diets through the CNCPS v.3.0 and CPM Dairy version of the CNCPS. However, this mean production ME value is still only 0.96 of the mean ME of diets calculated from tabulated ME values of feeds measured at the maintenance level of feeding used in AFRC (1993) and NRC (1988). Both versions of the CNCPS contain no level of feeding correction applied to these predicted production level diet ME values before matching them with dairy cow ME requirements specifically stated by NRC (1988), p.9, to have been adjusted for use with ME values measured at maintenance, as discussed in Alderman et al. (2001b). The effects of this failure to apply the appropriate correction for feeding level effects are discussed in Alderman et al. (2001b).

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STRESZCZENIE

Krytyka „Cornell Net Carbohydrate and Protein System" ze szczególnym odniesieniem do bydła mlecznego. 2. Model trawienia po-żwaczowego

Według modelu trawienia po-żwaczowego w „Cornell Net Carbohydrate and Protein System (CNCPS)" oblicza się wchłanianie składników pokarmowych w jelicie cienkim, pochodzących z komórek drobnoustrojów, pozostałych resztek paszy po trawieniu w żwaczu oraz wydzielonych do przewodu pokarmowego związków endogennych, a następnie bierze się pod uwagę tylko jedną grupę składników pokarmowych, a mianowicie wchłonięte aminokwasy (AA). Wynika to stąd, że pozornie strawne białko, węglowodany i tłuszcz są łączone do obliczania sumy strawnych składników pokarmowych (TDN), jako miary dostarczonej energii, która jest następnie przekształcana w energię strawną (DE), energię metaboliczną (ME) i energię netto laktacji (NEL). Przy bytowym poziomie żywienia tak obliczone wartości TDN pasz są mniejsze o 0,5 do 2,5% niż podane w tabelach NRC (1988). Przy typowym produkcyjnym poziomie żywienia (L = 4) przewidziane wartości ME są o około 6% niższe niż wartości podane dla bytowego poziomu żywienia, natomiast przewidywane wartości powinny być mniejsze tylko o około 5%. Model ten nie pozwala na bezpośrednie korzystanie z wartości podanych w tabelach NRC (1988) dla TDN, DE, ME i NEL pasz. Analizując precyzyjność modelu pod względem szacowania ilości pobieranej paszy wykazano, że dla wielu wprowadzanych parametrów ich ±10% zmienność nie miała istotnego wpływu na pobranie paszy wyrażone w TDN lub na pobranie białka metabolicznego (MP). Zmienność w poziomie białka ogólnego w dawce wpływała na dostarczanie do dalszych odcinków przewodu pokarmowego N i peptydów ze żwacza oraz białka metabolicznego pochodzącego z nie rozłożonego w żwaczu białka pobranego z paszą (UIP). Stężenie azotu mocznikowego w osoczu i mleku wahało się w granicach ±20% z powodu przyjętego w modelu współczynnika, i zmienność ta była dwukrotnie większa niż przyjęta zmienność w procentowej zawartości CP. Zmiany w poziomie detergentowego włókna obojętnego (NDP%) wpływały na efektywny rozkład NDF (eNDF) i wydajność syntezy białka drobnoustrojów średnio w ±7,7%, podczas gdy zmienność degradacji frakcji A i B1 węglowodanów (CHO) nie miała wpływu na wielkość syntezy drobnoustrojów. Zmiany w zawartości skrobi (frakcja B1 węglowodanów) wpływały ilościowo na syntezę drobnoustrojów, lecz było to kompensowane przez zmniejszenie zawartości frakcji A (cukry i rozpuszczalne CHO) węglowodanów, gdy wszystkie pozostałe parametry nie ulegały zmianie. Zmiany w zawartości tłuszczu w diecie miały istotny wpływ na przewidywane wartości TDN i ME ze względu na wysoką wartość energii brutto tłuszczu i stosowany mnożnik (2,25) dla procentowej zawartości tłuszczu w dawce. Opublikowane kryteria CNCPS utrzymują, że można z wystarczającą dokładnością przewidzieć ilość wypływającego ze żwacza krów mlecznych azotu nie-amoniakalnego (NAN). Istnieją jednak słabe punkty w analizie statystycznej danych dotyczących NAN, szczególnie w przypadku łączenia danych dla rosnącego bydła z danymi dla krów mlecznych. Ostatnie prace wykazały, że ilość przepływającego ze żwacza NAN przyjęta w systemie CNCPS jest zawyżona przy skarmianiu diet zawierających trudno degradowane w żwaczu białko, ponieważ niedostatek białka degradowanego w żwaczu nie zmniejsza syntezy białka drobnoustrojów.