Updates to the Cornell Net Carbohydrate and Protein System Implications of Changes in Version 6.5-6.55 for Diet Formulation and Evaluation

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Abstract

The Cornell Net Carbohydrate and Protein System (CNCPS) is a software model for evaluation and formulation of ruminant diets, primarily for dairy and beef cattle. Development was initiated nearly 40 years ago (Fox, 2014), and CNCPS has undergone extensive and ongoing improvement ever since. The objective of this paper is to describe the more significant changes implemented in the recent updates to CNCPS v6.5 and v6.55, and to describe their implications for users of CNCPS. Our focus is on changes with significant implications for dairy, and to some extent beef, ration formulation and evaluation in terms of predictions of animal level performance outcomes.

To better understand those recent changes and their implications for CNCPS users, it is helpful to see them in a context relative to the origin and ongoing evolution of CNCPS. Thus the first portion of this paper provides a general overview of the development of CNCPS since its first release, along with a brief description of some of the more significant changes along the way. The second part discusses changes specific to CNCPS v6.5 and v6.55, and the implications for users. Especially when combined with earlier changes implemented in CNCPS v6.0 and v6.1, these changes produce significant departures from the predictions made by CPM v3 and earlier versions of CNCPS. Users of earlier versions of CNCPS such as CPM v3 are therefore strongly encouraged to note the extent of these differences, and to move to a platform implementing the new version to capture advantages of CNCPS v6.55.

Introduction

The first release of CNCPS was in 1990; CNCPS v1 was described in detail in four publications in 1992 (Fox et al., 1992, Russell et al., 1992, Sniffen et al., 1992) and 1993 (O'Connor et al., 1993). Prior to CNCPS, in North America the primary reference for estimates of dairy cattle nutrient requirements and supply from diet feedstuffs was the Nutrient Requirements of Dairy Cattle series, first published in 1945 as “Recommended Nutrient Allowances for Dairy Cattle” (NRC, 1945). Several textbooks were also commonly used, such as Morrison’s Feeds and Feeding (Morrison, 1956). Both the texts and the NRC publications described nutrient supply from feedstuffs as static tabular quantities, wherein feedstuffs had fixed nutrient content based

mostly on estimates of TDN and either the digestible protein or crude protein content, with fixed digestibility coefficients being applied. This static description of nutrients supplied by feedstuffs continued to be applied in the next six NRC revisions published from 1950 to 1989.
CNCPS represented an important advance in dairy cattle nutrition in several ways. First, it improved estimates of organic nutrient supply by applying an extensive fractionation scheme to protein and carbohydrates present in feed ingredients (Sniffen et al., 1992), and then applied dynamic ruminal degradation and intestinal digestion rates to these fractions. The extent of ruminal digestion (**RD**) in CNCPS was determined by integrating the ruminal degradation rate (**k_d**) with the ruminal passage rate (**k_p**) using the equation $RD = k_d / (k_d + k_p)$. Secondly, and uniquely at the time, a kinetic fermentation sub-model was applied to estimate the yield of fermentation products and which considered ruminal degradation of both protein and carbohydrate (Russell et al., 1992). Intestinal digestibility of feed "bypass" fractions was then calculated by coefficients applied to undegraded material flowing from the rumen. This approach rendered both microbial and TDN yield as more dynamic estimates, sensitive to chemical composition of feedstuffs in terms of both quantity and digestion kinetics, and to ruminal passage rate which was linked to dry matter intake level relative to bodyweight, diet forage content, and particle size.

CNCPS also facilitated improved estimation of animal requirements, utilizing sub-models for physiological functions including maintenance, growth, pregnancy, lactation, body reserve change, rumen and intestinal digestion, and metabolism. Thus, CNCPS improved the precision of estimates of both nutrient supply and animal requirements. After the publication of the seminal 1992 papers, these aspects continued to be the subject of continuing efforts by the Cornell modeling group, which expanded to include scientists from University of Pennsylvania, and from Miner Institute. This resulted in the adaptation at the University of Pennsylvania of a version of CNCPS v.3 that culminated in the release the Cornell-Penn-Miner (**CPM**) Dairy v.1 platform in 1998. The deployment of CNCPS as a dynamic system used by researchers, educators, and industry field nutritionists was a forerunner of the broader adoption of more dynamic approaches to cattle nutrition. Both the 1996 Beef NRC and the 2001 Dairy NRC committees moved away from tables of static values and implemented more dynamic approaches to estimating nutrient requirements. The 1996 Beef NRC publication included much of the CNCPS model itself, and the 2001 Dairy NRC developed its own dynamic model, which included some sub-models from the CNCPS such as the growth sub-model and the energy reserves sub-model (Fox, 2014).

During the remainder of the 1990s and the early 2000s improvements continued to be implemented that enhanced precision of the model predictions. A major improvement was increased precision in predicted maintenance requirements by the incorporation of a revised environmental sub-model implemented in CNCPS v5 in 2003 (Fox and Tylutki, 1998). Among other important advances in the CNCPS during the 2000 decade was the implementation in CNCPS v5of a sub-model to account for changes in body tissue energy and protein content when estimating diet allowable milk yield (Tedeschi et al, 2006). Noteworthy was the first introduction of a fatty acid sub-model in the CPM Dairy v3 version. Feed carbohydrate fractionation was also updated in CPM Dairy v3 (Tedeschi et al., 2008), which was otherwise based on CNCPS v5.

It should be appreciated however, that the ongoing efforts to improve the model have not all involved entire new sub-models, but also incremental alteration of existing model components, for instance the handling of ruminal nitrogen deficits (Tedeschi et al., 2000), the prediction of dry matter intake (Roseler et al., 1997), and amino acids efficiency of use (Fox et al., 2004). CNCPS v5 was revised to v6.0 at the end of 2005 (Tylutki et al., 2008, Fox, 2014). The fatty acid sub-model and carbohydrate fractionation earlier implemented in CPM v3 were adapted into CNCPS v6.0, albeit with some modest differences. The fat sub-model involved changes in the estimation of TDN from fat (previously estimated by applying a 95% digestibility to apparently digested fat determined as (intake ether extract – fecal ether extract)). In the v6.0 implementation of the fat sub-model, TDN from fat is derived by apportioning ether extract to 3 components: glycerol (partitioned to the absorbed carbohydrate (**CHO**) pool), pigments and waxes (assumed indigestible), and individual fatty acids (**FA**). So rather than calculating TDN from fat based on 95% digestibility of the total ether extract, there was now a portion of that total that was treated as carbohydrate, and a portion that was removed from contribution to TDN completely. Another change in CNCPS v6.0 was an update of the passage rate equations (Seo et al., 2006).

By 2010 a revised version of CNCPS v6.0 was available, CNCPS v6.1, described in Van Amburgh et al. (2010). CNCPS v6.1 further differentiated the organic acid fractions in feeds, and it included significantly reduced degradation rates for some carbohydrate fractions. Most of these changes applied to soluble feed fractions, for example reducing the k_d for sugars from 300%-500% per hour to 40%-60%/h, and the k_d for soluble true protein from 130%-300%/h to 10%-40%/h. CNCPS v6.1 also implemented an altered equation for NFC by assuming that the NDF determination had been made with sodium sulfite, so the equation for NFC no longer subtracted the NDIP from NDF before subtracting the NDF from total feed quantity to determine NFC. This change reduced the NFC content somewhere on the order of ~4% typically. A major shift occurred in CNCPS v6.1 with the assignment of soluble feed fractions to the liquid passage pools. Because the liquid pool moves faster than the solid pool and thus rumen retention time is decreased, this change increased the undegraded feed pool and decreased the extent of microbial degradation / ruminal fermentation. Additional changes involved modifications to the feed library by repartitioning the soluble protein pool, which also contained greater amounts of true protein based on reevaluation of assays for soluble true protein. Taken together, the changes implemented in v6.1 resulted in decreased estimates of microbial yield, which required field users to adjust their expectations somewhat about the proportion of metabolizable protein (**MP**) derived from microbial (reduced) versus undegraded ruminal bypass protein (increased proportion of MP). The decreased extent of ruminal degradation of protein also reduced the ruminal ammonia pool and the ruminal nitrogen balance.

Also updated in CNCPS v6.1, with a big impact for users, were changes that affected predicted animal growth. Diets formulated with CNCPS for growing dairy heifers were known to result in over-fattening of heifers. Several changes in v6.1 significantly reduced over-formulation of metabolizable energy (**ME**) that occurred in earlier versions of CNCPS. A major change involved the calculation of the maintenance requirement. The maintenance requirement is affected by previous plane of nutrition, largely due to energetic costs of the gut. To model this, previous versions of CNCPS used body condition score (**BCS**) as a proxy for previous plane of nutrition, so that as the input BCS increased so did maintenance requirement. This link between BCS and maintenance requirement resulted in excessive increases in estimated maintenance energy requirement, so available energy supply was partitioned incorrectly to maintenance and thus not applied for growth. In v6.1 this link to BCS was eliminated, and BCS no longer was tied to maintenance energy requirement. As a result, more energy was partitioned to growth, reducing the estimated amount of ME necessary to achieve a desired daily gain (**ADG**) (Van Amburgh et al., 2010). The equation used to calculate surface area was also changed, which affected estimated heat loss. Taken together, these changes reduced the estimated ME required to achieve a given ADG; the more accurate requirement results in less over-formulation of ME supply and thus induces less fattening. Further changes in ruminal passage rates, discussed below under updates made in CNCPS 6.5, are expected to make the model even more accurate when formulating diets for growing animals and further minimize risk of overfat growing animals.

Recent Updates Implemented in CNCPS V6.5 & V6.5

More recently, the Cornell modelling group, led since 2006 by Dr. Mike Van Amburgh following the retirement of Dr. Dan Fox in 2005, released the latest version(s) of CNCPS, CNCPS v6.5 and v6.55. These releases implement a number of changes which are described in detail in Higgs et al., (2015) and Van Amburgh et al. (2015a). The changes have substantial impact on the formulation and evaluation of dairy cattle rations when CNCPS is used. The nature of the more significant changes, and their implications for ration formulation and evaluation are described below.

NDF_{OM}

In its original conception, NDF calculations in CNCPS were intended to be made on an ash free basis (Sniffen et al. 1992). However, the ash free aspect of NDF was never implemented in commercial laboratories as part of routine feed analysis, nor therefore in subsequent implementations or evaluation of the CNCPS. In CNCPS v6.5, NDF application is once again returned to an ash-free basis (NDF_{OM} = NDF on an organic matter basis, i.e. ash free NDF.)

Implication: As a result of including ash in NDF determinations, the NDF pool has previously been overestimated by the amount of included ash. Users of CNCPS v6.5 should be aware that the ash free NDF pool, NDF_{OM}, will be slightly smaller than the NDF_R (NDF_R = NDF residue, not ashed) value used previously. Thus, benchmarks for acceptable NDF content (such as minimum NDF% of DMI for instance) should be slightly reduced from previous expectations.

Users should also be aware that when NDF content of a feed is overestimated due to ash contamination there is an effect on the calculated k_d for NDF. Because both the rate and the extent of NDF digestion are important in estimating ME supply and microbial protein yield, to ensure CNCPS accurately estimates both, users should be requesting NDF analysis on an organic matter basis. This requires the laboratory to ash the samples, which adds time and expense to the analysis. However, some laboratories now have done enough NDF_{OM} analyses to have developed NIR calculations for NDF_{OM}.

uNDF / iNDF

CNCPS applies the ruminal NDF degradation rate (k_d) to the “potentially digestible” portion of NDF (**pdNDF**), not to the total NDF amount. pdNDF is the NDF pool remaining after subtracting out the estimated indigestible NDF (**iNDF**). Historically, the amount of iNDF has been estimated as lignin x 2.4 (Sniffen et al., 1992), referred to as $iNDF_{2.4}$. However, research reported by Raffrenato et al. (2009) found that when improved analytic techniques were used iNDF expressed as a ratio to lignin was variable and typically greater than 2.4. Furthermore, the ratio of lignin to undigested NDF (**uNDF**) was variable across forage family and stage of maturity. The authors attributed these findings to digestibility not being simply a function of lignin content, but is also affected by the extent of cross linking of lignin, hemicellulose, and phenolic compounds. Therefore in CNCPS v6.5 the use of lignin x 2.4 as an estimate of iNDF of forages was replaced by $uNDF_{240}$, which is NDF residue after 240 hours digestion (undigested at 240h, thus presumed indigestible). For concentrates, the estimate of uNDF is uNDF at 120 hours, i.e. $uNDF_{120}$. The use of $uNDF_{240}$ or $uNDF_{120}$ in place of $iNDF_{2.4}$ improves the accuracy and utility of both uNDf and pdNDF in evaluating rations. This improvement accrues in part from the ability of uNDF240 to capture environmental effects on plant growth that promote changes in the extent of crosslinking, not simply the extent of lignification.

Implication: Because uNDF is a more accurate estimate of iNDF it improves the accuracy of predicted nutrient supply in two ways. First, it allows a better estimate of the amount of pdNDF, the digestible portion of NDF. Secondly, it improves the estimation of pdNDF ruminal degradation rate because determination of the pdNDF k_d is considerably influenced by the iNDF amount (Raffrenato et al., 2009, Raffrenato and Van Amburgh, 2010). Both the amount of pdNDF and the pdNDF k_d are major determinants of diet digestibility, as well as of ME supply and microbial yield. Improved accuracy in the determination of pdNDF and the pdNDF k_d thus enhances the accuracy of predictions of animal performance. Higgs et al. (2015) reported that CNCPS ME allowable milk was very sensitive to increased forage pdNDF; increased diet forage pdNDF content was associated with decreased ME allowable milk. the use of $uNDF_{240}$ instead of $iNDF_{2.4}$ to quantify uNDF contributes to more accurate estimates of ME allowable milk or ME allowable growth in CNCPS v6.5. Dry matter intake is also associated with uNDF, mediated by uNDF effect on gut fill; more accurately knowing the quantity of uNDF in diet formulations can be helpful in optimizing intake or troubleshooting performance problems related to intake (Cotanch et al., 2014). These advantages of $uNDF_{240}$ accrue from the value’s ability to better capture environmental and agronomic effects on plant digestibility than $iNDF_{2.4}$, and thus it provides nutritionists a better tool to assess diet digestibility and calculate diet nutrient content.

Raffrenato Rate Calculator

CNCPS originally applied a coefficient to pdNDF which represented a first order estimate of the rate of ruminal degradation of a single pdNDF (**CHO B3**) pool. Default values for this coefficient were originally supplied from published literature for feed fractions (Sniffen et al., 1992), with the proviso that "users may need to adjust these rates… based on their knowledge of factors that may result in unusually low or high digestion." Most such adjustments, when made by field users, were essentially educated guesses based on experience and intuition. Later Van Amburgh et al. (2003) provided an algorithm to calculate CHO B3 degradation rate based on a single digestion time point. This proved very useful for more accurately adjusting default "book" k_d values and provided commercial feed laboratories and users a method to better adjust ruminal digestion for specific feed samples. The Van Amburgh algorithm applied a first order coefficient to a single pdNDF pool linearized by a log-linear transformation, but the authors noted that the pdNDF pool appeared to be composed of two distinct pools, a "fast" and "slow" pool. In CNCPS v6.5 a new rate calculator, the Raffrenato Rate Calculator, has been implemented. This calculator requires that digestion at three time points be supplied, for forages @ 30, 120, and 240 hours, for concentrates @ 12, 72, and 120 hours. The Raffrenato rate calculator addresses this two pool composition of the pdNDF fraction by calculating a k_d for each pool, and then integrating them as a weighted average to a single k_d applied to the entire pdNDF pool (Raffrenato and Van Amburgh, 2010). While applied to a single pdNDF pool in the current CNCPS v6.5, this calculator will be utilized in the next version of CNCPS, version 7 (in development and not yet released) and will apply separate k_d values to a two pool (fast and slow) pdNDF composition.

Implication: The implementation of this rate calculator is accomplished by an add-on simulation software, VenSim, (Ventana Systems Inc., Belmont, MA) that must be installed and linked to CNCPS v6.5 software. Because of this, the k_d values derived from the Raffrenato rate calculator are not available from feed laboratories. Where commercial feed labs are supplying CHO B3 rates they are deriving them with the Van Amburgh 2003 algorithm or an alternate algorithm. Thus the laboratory supplied k_d values do not match the Raffrenato derived values, nor are they as accurate, although preferable to using the default "book" values in the library. Additionally, the Cornell CNCPS library was completely revised with the release of CNCPS v6.5 (discussion below), but that revision occurred before the deployment of the Raffrenato rate calculator, thus the k_d values in the library are not consistent with the newer more accurate rates obtained when three digestion time points and the Raffrenato calculator is used. Furthermore, the Raffrenato calculator uses the $uNDF_{240}$ value as the iNDF value in calculating k_d. The $uNDF_{240}$ estimate of iNDF tends to be larger than estimates of $iNDF_{2.4}$, which are based on the lignin ratio. iNDF is very important in the estimation of k_d (Raffrenato et al., 2009), and differences in the iNDF pool size affect the calculated k_d. Therefore, it becomes important to apply the rate calculators consistent with the iNDF determination used in their development. Consistent with this, the rates derived by the Raffrenato calculator tend to be slightly greater, but are applied to a somewhat smaller pool of pdNDF (because the iNDF subtracted from the total NDF is typically somewhat greater for $uNDF_{240}$ than for $iNDF_{2.4}$). This implies that users should use either $iNDF_{2.4}$ or $uNDF_{240}$ consistent with the algorithm they use to determine the CHO B3 k_d rate or there will be additional error introduced into the estimation of NDF digestion.

Revised CNCPS Feed Library – Updated Feed Composition:

The k_d values in the original CNCPS feed library (Sniffen et al., 1992, O'Connor et al., 1993) were extensively updated by the developers of CPM v3. That same CPM v3 library was incorporated into the CNCPS feed library in CNCPS v5, but values for many nutrients continued to be from the original library. Now, the release of CNCPS v6.5 is accompanied by the most extensive revision of the organic feed fractions in the feed library since the release of CNCPS v1. This revision was conducted on the organic feed components to reflect current analytic values for feed components used in CNCPS and for which analyses are available from commercial laboratories. The intent of the effort was to ensure that library values were consistent with contemporary commercial laboratory results and databases, with the objective to improve CNCPS predictions of nutrient supply and thus animal performance (Higgs et al., 2015). Mineral values were not updated, and remain as in CNCPS v6.1, which incorporated the 2001 NRC mineral system into CNCPS (Van Amburgh et al., 2010). Beyond simply updating feed composition values however, this library revision contains changes that affect ration formulation and evaluation (Higgs et al., 2015).

Revised CNCPS Feed Library: Soluble Protein Fractions PA Repartitioned to PA1 & PA2:

First, in CNCPS v6.0 the soluble protein pool (**PA**) contained NPN, peptides, and free amino acids, all assumed to be completely degraded in the rumen. In the revised library, soluble protein is now partitioned into two sub-fractions (Higgs et al., 2015). The NPN sub-fraction is now redefined as ammonia only (**PA1**) and is smaller than the previous NPN fraction, which formerly contained peptides and free amino acids also. The redefinition of the NPN fraction was accompanied by repartitioning the peptides and free amino acids to a soluble true protein fraction designated **PA2**. (All soluble protein and carbohydrate fractions now carry the A designation.) This change was prompted by new methodology to determine true protein content in the soluble fraction, and by literature reports that significant amounts of amino acids were supplied to the intestine by the soluble protein pool. Commercial feed laboratory assays can routinely determine ammonia, facilitating more accurate analytics for these two fractions. For both PA fractions in CNCPS v6.5 the k_d values were reassessed to ensure that MP predictions were accurate. New k_d values for PA1 were set at 200%/h (reduced from 10,000%/h), while the k_d values for PA2, which contains soluble true protein, range from 10-40%/h. Soluble true protein, PA2, has a high rate of passage because it moves with the liquid phase (discussed below), and is now modeled as a significant contribution of rumen undegraded protein and amino acids to the MP supply.

Implication: The recharacterization of the soluble protein pool and the revised rates applied to it result in greater predicted supply of rumen undegraded protein (RUP) flowing to the intestine, although in evaluating the model the Cornell group found that rumen undegraded nitrogen flow to the intestine was slightly over-predicted, but offset by a slight under-prediction of microbial nitrogen flow. The increased flow of RUP increases the proportion of MP derived from RUP relative to the proportion from microbial yield, so users should now expect to see less than 50% of MP derived from microbial protein. A related shift is that ruminal ammonia supply is decreased, so users should monitor the rumen ammonia balance. Generally, the decrease in rumen ammonia does not require altered ration formulations unless diets are balanced at very low levels of crude protein. Nonetheless, MP from microbial protein should usually be greater than 45%. Lower levels might indicate either a problem with fermentable carbohydrate supply, a shortage of rumen ammonia, or overfeeding of RUP. For users, these changes in CNCPS v6.5 improve the precision and accuracy of the predicted MP supply and allow greater confidence in formulating diets with quite low crude protein content. Indeed, a trial reported at the 2016 American Dairy Science Association joint meeting in 2016 reported a mean milk yield of 44 kg of energy corrected milk when cows were fed 14.7% crude protein diets with conventional soybean protein sources, formulated using CNCPS v6.5 (Fessenden et al., 2016). Milk yield overall for primiparous animals in that study ranged from 30 to 54 kg/d; multiparous cattle milk yields ranged from 39kg to 73 kg (M. E.Van Amburgh, personal communication). Such yields on protein efficient diets confer economic and environmental benefits and are facilitated by the changes implemented in CNCPS v6.5.

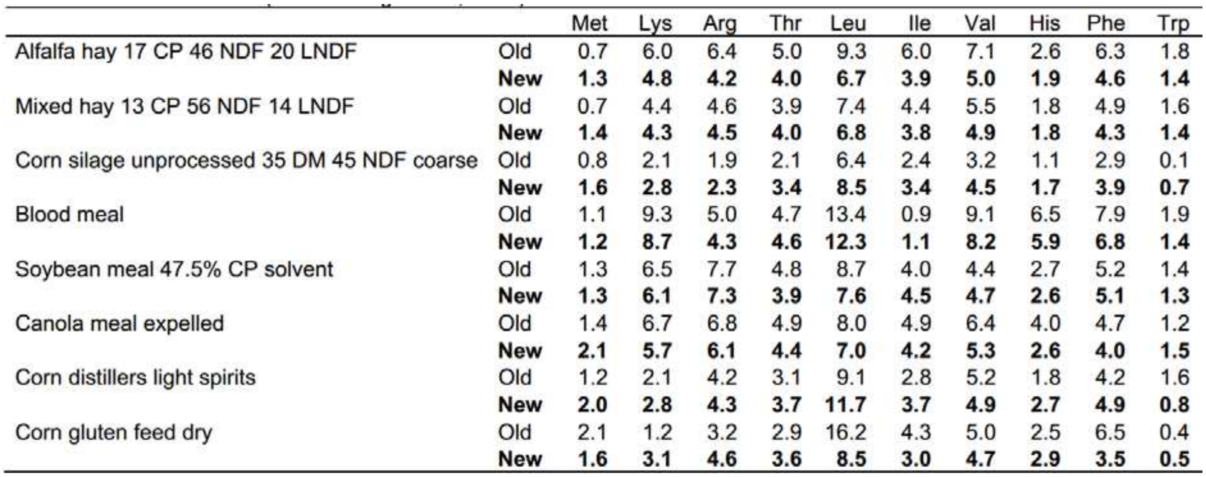
As noted above, these changes also reduced the estimated rumen ammonia supply from intake nitrogen; the Cornell group recommends maintaining rumen ammonia balance at 110% - 120% of requirement (Van Amburgh et al., 2015b). The need to maintain rumen N balance above requirement is partly related to assumption of steady state by the current model. In the next version (CNCPS v7), a more dynamic model of rumen ammonia status will be implemented that will account for time-varying postprandial ammonia supply. It is presumed that rumen ammonia might vary both above and below the overall requirement estimated at steady state, and therefore to prevent deficiencies at some time points it may be necessary to maintain the supply above mean daily requirement. Rumen ammonia status will especially need to be monitored as users formulate diets for high producing cows at less than 15% crude protein. Users are advised to monitor MUN for specific groups as well (not simply whole herd bulk tank values) as an indicator of ammonia supply.

Revised CNCPS Feed Library – Amino Acid Content Updated & Now Expressed as %CP:

A second major feed library change is related to amino acid (**AA**) content of feedstuffs, previously determined and expressed as a percentage of insoluble protein residue after acid hydrolysis. Amino acids are now determined on a whole feed basis and expressed as a percent of crude protein (Higgs et al. 2015), making analyses easier and less expensive to obtain and enter. Furthermore, at and before the time the original O'Connor et al. 1993 compilation of feed AA content was created AA analytic protocols used rendered a significant amount of methionine (**Met**) unrecoverable, and thus the original library significantly underestimated the Met content of most feeds. The Met content of most feeds is significantly higher in the revised library.

<u>**Implication:**</u> Because feed samples are not routinely submitted for amino acid analysis, the library is extensively relied on to populate feedstuff amino acid values when diets are evaluated or formulated. The changes in diet amino acid supply are therefore important, especially for Met, and especially when users are interested in evaluating diets relative to potential milk protein yield. However, the changes in supply of Met, as well as lysine (**Lys**), are partly offset by changes in their efficiencies (discussed below). Despite the increased Met supply in basal diets, the need for rumen protected amino acid supplementation to meet recommended optimum levels remains likely for many diets, as discussed below.

Table 1. *Comparison of Old and New Amino Acid Profiles from Selected Feeds in the CNCPS Feed Library. Values from the old library are expressed as % buffer insoluble residue. Values from the new library are expressed as % CP from the whole feed. (Van Amburgh et al. 2013)*



		Met	Lys	Arg	Thr	Leu	Ile	Val	His	Phe	Trp
Alfalfa hay 17 CP 46 NDF 20 LNDF	Old	0.7	6.0	6.4	5.0	9.3	6.0	7.1	2.6	6.3	1.8
	New	**1.3**	**4.8**	**4.2**	**4.0**	**6.7**	**3.9**	**5.0**	**1.9**	**4.6**	**1.4**
Mixed hay 13 CP 56 NDF 14 LNDF	Old	0.7	4.4	4.6	3.9	7.4	4.4	5.5	1.8	4.9	1.6
	New	**1.4**	**4.3**	**4.5**	**4.0**	**6.8**	**3.8**	**4.9**	**1.8**	**4.3**	**1.4**
Corn silage unprocessed 35 DM 45 NDF coarse	Old	0.8	2.1	1.9	2.1	6.4	2.4	3.2	1.1	2.9	0.1
	New	**1.6**	**2.8**	**2.3**	**3.4**	**8.5**	**3.4**	**4.5**	**1.7**	**3.9**	**0.7**
Blood meal	Old	1.1	9.3	5.0	4.7	13.4	0.9	9.1	6.5	7.9	1.9
	New	**1.2**	**8.7**	**4.3**	**4.6**	**12.3**	**1.1**	**8.2**	**5.9**	**6.8**	**1.4**
Soybean meal 47.5% CP solvent	Old	1.3	6.5	7.7	4.8	8.7	4.0	4.4	2.7	5.2	1.4
	New	**1.3**	**6.1**	**7.3**	**3.9**	**7.6**	**4.5**	**4.7**	**2.6**	**5.1**	**1.3**
Canola meal expelled	Old	1.4	6.7	6.8	4.9	8.0	4.9	6.4	4.0	4.7	1.2
	New	**2.1**	**5.7**	**6.1**	**4.4**	**7.0**	**4.2**	**5.3**	**2.6**	**4.0**	**1.5**
Corn distillers light spirits	Old	1.2	2.1	4.2	3.1	9.1	2.8	5.2	1.8	4.2	1.6
	New	**2.0**	**2.8**	**4.3**	**3.7**	**11.7**	**3.7**	**4.9**	**2.7**	**4.9**	**0.8**
Corn gluten feed dry	Old	2.1	1.2	3.2	2.9	16.2	4.3	5.0	2.5	6.5	0.4
	New	**1.6**	**3.1**	**4.6**	**3.6**	**8.5**	**3.0**	**4.7**	**2.9**	**3.5**	**0.5**

Amino Acid Tissue Content

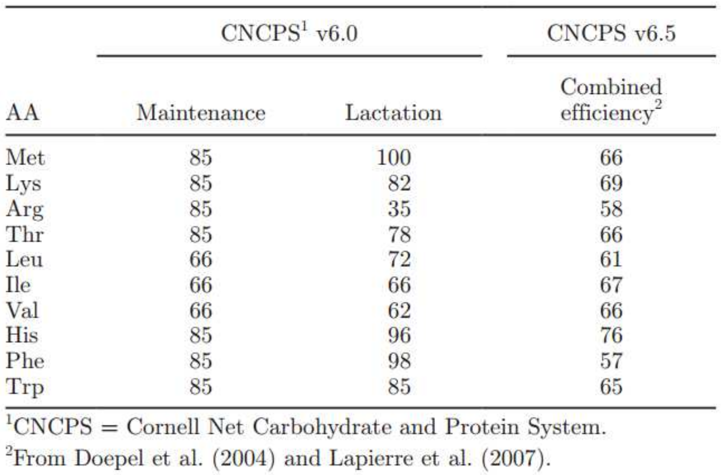
Tissue amino acid composition values were originally set out in O'Connor et al. (1993), and later updated in version 5 (Fox et al. 2004). Accompanying the updated CNCPS library amino acid composition of feedstuffs described above, the amino acid tissue composition was also updated to newer values. Changes in tissue AA composition are quite modest (Van Amburgh et al., 2015), with slight reductions in Met (now 1.79g/100g crude protein vs 1.97g previously) and in Lys (now 6.26g/100g vs. 6.37 g/100g crude protein previously).

One additional change implemented in CNCPS v6.5 is the provision to incorporate amino acids from mobilized body tissue into the overall amino acid supply (Van Amburgh et al., 2015b)This is implemented when modeling negative energy balance, i.e. when the "Target" body condition score is set lower than the "Current" body condition score, such as is fairly common when modeling early lactation diets. When mobilization of body reserves is thus modeled a small amount of lean tissue is mobilized and contributes amino acids to the net supply.

Amino Acid Tissue Efficiencies Revised

More significant in terms of ration formulation, CNCPS v6.5 introduced a major change in amino acid efficiencies used in factorial calculation of the amino acid requirements. Amino acid efficiencies had last been updated in CNCPS v5. Until this version there were separate AA efficiencies for maintenance and lactation. Those efficiencies are now combined into a single amino acid efficiency based on work by Doepel et al. (2004) and Lapierre (2007). In addition to being a single coefficient in CNCPS v6.5, the combined efficiency is markedly reduced compared to the previous values, shown in Table 1 below.

Table 2. *Comparison of Amino Acid Efficiencies in CNCPS v6.0 and 6.5. Adapted from Van Amburgh et al. (2015)*



	CNCPS[1] v6.0		CNCPS v6.5
AA	Maintenance	Lactation	Combined efficiency[2]
Met	85	100	66
Lys	85	82	69
Arg	85	35	58
Thr	85	78	66
Leu	66	72	61
Ile	66	66	67
Val	66	62	66
His	85	96	76
Phe	85	98	57
Trp	85	85	65

[1] CNCPS = Cornell Net Carbohydrate and Protein System.

[2] From Doepel et al. (2004) and Lapierre et al. (2007).

<u>Implication:</u> Taken together, the changes regarding amino acids, both in terms of the revised AA amounts and the changes in efficiencies, impact AA balance when rations are evaluated in CNCPS v6.5. However, the reduced efficiencies of AA use are somewhat offset by the increased amount of AA in the basal feeds in the revised feed library and by changes in protein pools and rates, both of which contribute to more AA available for absorption to metabolizable protein. Nonetheless, there is an impact on the extent to which rumen protected AA might be needed when balancing rations for amino acids, as discussed below.

Amino Acid Optimums For Milk Protein Revised:

The changes described above for both amino acid composition of feedstuffs and efficiencies of utilization required reconsideration of optimum diet concentrations of lysine and methionine. As a result the optimal values for ratios of these amino acids to metabolizable protein, or to other amino acids, have changed with CNCPS v6.5. Values derived from a breakpoint analysis of data from a dataset of dose response experiments for milk protein yield are modestly different from values used with CNCPS v6.0 and the former Cornell library. For milk protein yield, the CNCPS v6.5 optimums for Lys and Met respectively are 7% and 2.6% of metabolizable protein;

the values used for CNCPS v6.0 previously were 6.74% and 2.31% for Lys and Met respectively (Van Amburgh et al., 2015a). The recommended ratio of Lys:Met has also changed and is set at ~2.7:1 in CNCPS v6.5. This reflects the relatively modest change in Lys supply, and the greater magnitude of change in Met supply. Values for milk protein concentration in CNCPS v6.5 are also different from previous optimum values, with Lys and Met respectively being optimum at 6.77% and 2.85% of metabolizable protein, a change from the values of 6.68% Lys and 2.4% Met used previously.

In addition, the Cornell group has suggested that determination of an appropriate supply of amino acids to optimize milk protein yield may be more effectively made relative to energy supply instead of as a ratio with MP (Van Amburgh et al., 2015a). They have suggested that the ratio of Met to metabolizable energy should be in the range of 1.12 to 1.15 grams/Mcal ME. They propose that after estimating that amount of Met supply, the ratio of the breakpoints of Lys:Met for milk protein yield be used to determine the required Lys amount (7% MP Lys: 2.6% MP Met = ~2.7 Lys:Met). For milk protein concentration as opposed to yield, Met supply would be greater, perhaps on the order of about a 10% increase (2.85/2.6 =1.096). The Lys amount calculated from the ratio of the optimums for milk protein concentration as above would be 6.77% Lys / 2.85%Met, or ~2.38 Lys:Met. Achieving levels of inclusion required to optimize either milk protein yield or concentration will often require use of rumen protected amino acids.

Protein B2 kd Linked to Cho B3 kd

Protein B2 (**PB2**) fraction is slowly degraded true protein, and is a combination of what were previously two pools associated with cell wall (fiber) in CNCPS v6.1, PB2 and PB3. In CNCPS v6.5 those two pools are collapsed to a single pool of slowly degraded protein, PB2, and assigned the same k_d as pdNDF (Higgs et al., 2015). This change does not have a large effect on ration evaluation or formulation.

Passage Rate: Soluble Feed Fractions Reassigned To Liquid Pool

In CNCPS v6.1 and earlier, soluble feed fractions were assigned to flow out of the rumen at the solid passage rates. This was a somewhat atavistic error, as consensus is that the original intent when CNCPS was developed was to assign them to the liquid pools. All soluble feed fractions are now assigned to flow at the liquid pool passage rate. This reassignment of soluble fractions, especially the newly portioned PA2 fraction, does make a significant difference in the extent of ruminal digestion. The liquid pool flows several times faster than the forage or concentrate solids, and thus escapes the rumen more quickly and is therefore subject to less ruminal degradation. This effect was discussed above for soluble protein fractions. The greater escape of soluble sugar further reduces microbial yield, as described previously for soluble protein. While this affects the relative proportions of MP from RUP and microbial yield, the intestinal digestibility of the soluble fractions is set to 100%, so little change in net total MP or ME occurs.

Passage Rate: Forage Kp Equation Updated in CNCPS v6.55

CNCPS applies three ruminal passage rates in the estimation of rumen digestibility, a passage rate to forage solids, one to insoluble components of concentrates, and one to liquid passage of soluble diet components. In CNCPS v6.55 the passage rate for forages has been changed from the rate equation developed by Seo et al. (2006) to one (NorFor) developed as part of the Nordic Feed Evaluation System Series (Van Amburgh et al., 2015b). This change was prompted by observations that animals on higher forage diets, such as replacement heifers and dry cows, which tend also to be at more moderate intakes than high producing lactating cattle, were being over fed energy on diets formulated with CNCPS, even after the changes affecting energy requirements implemented in CNCPS v6.1. The NorFor equation renders the passage rate for forages much lower. In an early evaluation of the impact of the change, the Cornell modelling group found that in one set of data the change decreased forage passage rate from ~4.8%/h to 1.7%/h (Van Amburgh et al., 2015b). This large decrease results in an approximate three-fold longer estimated rumen residency time for forage, with the further result that forages are estimated to undergo more extensive ruminal digestion / degradation. The consequence of this is to increase the estimate of TDN supplied by forage, and thus increase diet ME supply significantly. The difference in estimated ME supply is posited as the reason animals consuming higher forage formulated in earlier versions of CNCPS (and with dairy NRC (2001)) tended to fatten (Van Amburgh et al., 2015b).

The additional energy supply derived from more extensive forage degradation with the new passage rate equation was modestly, but not completely, offset by a decrease in the coefficient for intestinal digestibility of NDF, which was reduced from an intestinal digestibility of 20% to 5%. This lower intestinal digestibility is consistent with literature reports (Van Amburgh et al., 2015b), and makes sense because ruminants, like other mammals, do not have intestinal cellulases necessary for post-ruminal fiber digestion. Nonetheless, the net effect of the change in passage rate and intestinal digestibility is to increase the yield of ME from forage, and this effect is more considerable in higher forage diets. The increase in predicted ME supply is also accompanied by a modest increase in metabolizable protein, but this is not a large enough increment in most cases to affect ration formulation very much.

Implication: This change will have a greater impact on diets containing higher forage amounts. This change has not been extensively validated in heifers yet, but field experience suggests that this has improved the estimation of energy supply with the effect of minimizing excess energy supplied in heifer rations formulated in CNCPS v6.55. This change has been evaluated on a limited basis for dry cows in trials at Cornell, where predicted energy balance appeared to be more consistent with observed energy balance than predictions using the previous passage rate equation (Van Amburgh et al., 2015b). Thus it appears that this change will allow formulation of dry cow and heifer diets with a more accurate estimation of energy, and will therefore decrease the potential for fattening. There has not been validation work done of this specific change in lactating cows, but field experience seems to suggest that the change increases accuracy of ME supply and energy allowable milk predictions. But, CNCPS now requires more careful attention to animal inputs. For example, inputs for age, current and mature bodyweight, and lactation number all affect the calculation of the expected daily gain. We have found that when these inputs are made correctly, as well as other inputs such as milk composition and "target" body condition score, ME predictions made with the NorFor equation implemented are reasonably accurate, although we have not evaluated this statistically. Users should note that the term "target body condition score" in the animal inputs really refers to the expected condition score at a future time, in most model scenarios not to a desired "target".

Fatty Acid Digestibilities Reduced in CNCPS 6.5

A very large change in the ME supply occurred in CNCPS v6.5 with changes in estimated fatty acid digestibilities. Fatty acids (**FA**) were previously calculated at a uniform 95% digestibility for all FA, however in CNCPS v6.5 variable individual fatty acid digestibilities are applied that range from 95.4% to a low of 58.6% (Van Amburgh et al., 2015a). Typically the weighted average digestibility of diet fatty acids is now somewhere between 72% and 74%. This marked reduction in FA digestibility, coupled with the earlier reassignment in v6.0 of glycerol to the carbohydrate pool, and the exclusion of pigments and waxes in ether extract as indigestible, results in a drastically reduced energy yield from fats, especially basal fats in forage that can contain significant amount of indigestible pigments.

Implication: This change has, in the author's experience, been the reason some field users switching to CNCPS v6.5 from CPM v3 or earlier CNCPS versions may become unsettled with the predicted ME and ME allowable milk. Van Amburgh et al. (2015a) reported that the fatty acid digestibility change reduced ME allowable milk 2 kg in their assessment of the change, although in practice the reduction will depend on the composition of the diet, especially of the diet ether extract. In corn silages, a typical amount of ether extract might be ~3.2% of DM, of which about 30% is no longer contributing as "fat" to the estimate of ME supply because the actual fatty acid content of corn silage typically totals only about 2.2% of DM or ~70% of the ether extract. For hay crop forages the decrease in predicted ME yield is even greater, because while hay crops, depending on the species and preservation method, contain a similar amount of ether extract as corn silage, the pigment/wax content is greater (~42% of the ether extract), and the fatty acid content is only in the neighborhood of 50% of ether extract. These estimates are based on the values in the updated CNCPS library. Given the extensive reexamination of feed composition it entailed, these estimates are expected to reasonably reflect the difference in the change in fatty acid digestibilities. Nonetheless, in spite of marked reductions in estimated ME supply from ether extract, taken as a whole with other changes such as the revised forage passage rate, CNCPS now has improved accuracy in predictions of ME supply.

Model Evaluation: How Accurate and Precise is CNCPS v6.55?

Van Amburgh et al (Van Amburgh et al., 2015a) reported an evaluation of the model against 4 different independent datasets. The Cornell group evaluated the accuracy and precision of the model with respect to predictions of milk when either ME or MP was first the limiting nutrient (Van Amburgh et al., 2015a). Data from 250 treatment groups from 55 different studies and 15 different farms were used for the evaluation. The reported R^2_{BLUP}, which indicates the proportion of variation in observed milk explained by the model and includes accounting for the "study effects" of studies included in the validation dataset, was quite high, 0.97 for either ME or MP being first limiting for milk yield. They also reported a coefficient of determination based on model predictions without adjusting for individual study effects, R^2_{MDP}. The R^2_{MDP} reported was 0.78 when either ME or MP was first limiting. When the study effect was accounted for, the root mean squared prediction error was 1.6 kg/d; if the total mean squared prediction error is considered, without considering variance due to study-specific effects, the root mean squared prediction error was 3.6 kg/d. In other words, the reported "noise" in the predictions was larger when the total variance in the predictions is assessed without accounting for the random effects of studies. One way for field nutritionists to consider this is to appreciate that the predicted study-specific effects can be thought of as similar to farm-specific effects. Overall the model is quite accurate in predicting to within 1.6 kg/d on average across all studies when study-specific random effects are accounted for. But, any specific study (or for users, farm) will have some random difference, of variable size, from the population average prediction accuracy. A measure of combined precision and accuracy, the concordance correlation coefficient (**CCC**), was applied to predictions when either ME or MP was first limiting. The CCC was reported as 0.83, which indicates very good ability to predict milk yield. Taken together, these metrics, as well as additional evaluation metrics not described here, imply that CNCPS v6.55 users can be confident that the updated model will perform well in field application, and is in fact more precise and accurate than previous versions.

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