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Amino acid needs of lactating dairy cows: Predicting limiting amino acids in contemporary rations fed to high producing dairy cattle in California using metabolic models

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ABSTRACT

The objectives were to predict amino acid (AA) profiles of intestinally delivered protein in California high group (*i.e.*, lactating but not yet confirmed to be in calf) dairy cattle fed contemporary rations using three metabolic models of dairy cows. This was done in order to predict limiting AA in dairy rations to determine if there was enough consistency in the nutrient profiles of these rations to support a common ruminally protected (RP) AA package to supplement similar rations. Nutrient profiles of 16 commercial high group dairy cow rations were evaluated, and limiting AA predicted by the metabolic models 'Amino Cow', 'CPM Dairy' and 'Shield'. Higher inclusion levels of corn products in rations increased the contribution of corn CP to the total CP content of the total mixed ration (TMR), from 0.20 to 0.40. Even though the lysine to methionine ratio decreased as more corn CP was included in the TMR, it did not have a major impact on the final predicted AA profile of metabolizable protein (MP), but MP delivery (g/d) to the duodenum was predicted to decrease with increased corn CP levels. None of the models predicted any affect of increased corn CP levels on milk components but, according to Shield, it did have an effect on milk yield which increased when the ratio of lysine to methionine in MP decreased. The sequence of AA limitation among rations was the same within model, but differed substantially among models. Methionine, isoleucine and lysine were predicted to be most limiting according to Amino Cow, CPM Dairy and Shield, respectively. There appears to be sufficient consistency in nutrient profiles among rations to support a ruminally protected AA complex to balance the model predicted AA profile in order to increase animal productivity and efficiency of utilization of nutrients. There is no absolute way to decide which model predictions are most correct. However because Shield predictions suggested a higher correlation between Lys and Met in MP and production, as well as predicted AA ratios to milk responses related to these ratios, use of the Shield predicted AA package is supported.

Abbreviations: AA, amino acids; ADF, acid detergent fiber; ADICP, acid detergent insoluble CP; CP, crude protein; DDG, dried distillers grains; DIM, days in milk; $dNDF_{30}$, 30 h ruminal *in vitro* aNDF digestibility; DHIA, Dairy Herd Improvement Association; DM, dry matter; EAA, essential AA; EE, ether extract; MCP, microbial CP; MP, metabolizable protein; NDF, neutral detergent fiber; aNDF, amylase-treated NDF; aNDFom, aNDF expressed free of residual ash; RP, rumen protected; SolCP, soluble CP; TMR, total mixed ration.

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1. Introduction

Over the past 10 years there has been a substantial increase in the number of motor vehicle fuel ethanol distillation plants in the Midwestern USA, primarily using corn grain as their feedstock, creating vast quantities of corn distillers' by-products. Dairy rations in many parts of the USA have long depended upon corn based feedstuffs (*e.g.*, corn grain, corn silage, corn gluten, as well as germ feeds and meals) and, with the widespread increase in use of corn dried distillers grains (DDG), it is not uncommon to find 300–400 g/kg of total crude protein (CP) in total mixed rations (TMR) originating from corn products.

Corn proteins have long been recognized to have an amino acid (AA) profile that is poorly matched to that of milk protein produced by dairy cows (Schwab et al., 1976; NRC, 2001), primarily due to its low lysine content. Belyea et al. (1989) demonstrated the high variability in nutrient content that is inherent to by-product feeds, mostly due to differences in processing methods among plants and changes in these methods over time. Increased CP levels in rations, as a result of increased inclusion of less expensive protein sources to keep ration costs low, or as a safety factor due to uncertainty of feed composition to ensure that animal requirements for limiting AA are met (St-Pierre and Thraen, 1999), may lead to increased excretion of N in urine and feces. This is in direct opposition to recent efforts designed to minimize negative impacts of dairy cows on the environment.

Researchers and nutritionists differ on which AA are limiting for milk production in dairy cattle, but studies have suggested lysine and methionine to be the most likely candidates (Burris et al., 1976; Schwab et al., 1976, 1982) followed by phenylalanine, isoleucine, threonine (Derrig et al., 1974; Vik-Mo et al., 1974; Nichols et al., 1998; Piepenbrink and Schingoethe, 1998; Liu et al., 2000) histidine and arginine (Vanhatalo et al., 1999). Balancing diets for MP is difficult using current metabolic models due to a lack of accurate predictability of intestinally absorbable AA needs and delivery. Models cannot fully account for variability among raw materials, cows, environment or their interaction, which limits the application of their predictions. However, more information is required regarding limiting AA, and the effect of supplementing them, and since large scale dose–response studies are very difficult to conduct with lactating cows, comparing model predicted limiting AA in various, well-defined, rations could help to understand and estimate nutrient supplies to the cows and make ration formulation based on AA levels in intestinally absorbed protein feasible. Since results from previous studies in which only lysine was supplemented were inconsistent (Robinson, 2010), and results from a study we conducted showed a substantial negative response (Swanepoel et al., 2010), it raises questions as to whether lysine is limiting in contemporary California dairy rations.

This study was an evaluation of feeding practices, including sampling of feeds and TMR on selected California herds, which were then evaluated with three metabolic models used by nutritionists, to determine model predicted AA profiles of intestinally delivered protein in order to identify limiting AA and to determine if there is enough consistency in the nutrient profiles of these rations to justify production of a ruminally protected (RP) AA complex which could provide cows with an 'ideal' dietary AA profile to improve animal production and efficiency.

2. Materials and methods

2.1. Farm, cows and management

A group of 24 potential dairy farm co-operators were identified in Tulare and Kings Counties (CA, USA), the two main milk producing counties of California. Dairies chosen for this initial list were judged to be representative of dairy farms in the respective counties and milked more than 1000 cows. From the total of 24 dairies, 16 were finally chosen based on an assessment of factors including ration composition, standard/level of management on the dairy (*i.e.*, accurate mixing and feeding records to determine amounts of feed mixed and TMR fed), use of computerized herd record and management systems and an organized structural outlay of the lactation pens. Each dairy had a consulting nutritionist responsible for formulating the ration, and care was taken during the selection process to select dairies with different nutritionists.

2.2. Sample collection

Three visits to each farm were scheduled to coincide with the regular Dairy Herd Improvement Association (DHIA) milk test. During the first visit, dairies were appraised and the managers informed of the procedures to follow. One of the high production pens was identified for use in the survey at each farm.

During the second visit, TMR preparation was observed before TMR samples were collected from the bunks as they was being fed to the specified pen. Six handfuls of TMR were collected at evenly spaced locations along the bunk-line, pooled and the entire sample quartered, keeping two opposite quarters for analysis. When TMR samples contained whole citrus pulp, large pieces were broken up by hand before quartering to ensure accurate sampling.

Commodity feeds and silages, mixed into the TMR, were identified and sampled by taking four to five handfuls of each. A 'golf club' hay probe (Seifert Analytical, Lodi, CA, USA) was used to take 12–16 core samples from all hays as well as oat, wheat and rice straws.

A second TMR sample was collected, after preparation was again observed prior to, or on the day of, regular DHIA milk testing following the same procedures as above. Highly variable wet commodities, such as green alfalfa chop, were also sampled a second time. As far as possible, the two sampling visits were scheduled at different feeding times during the day.

All feed and TMR samples were stored in a refrigerator and later transferred to a freezer (−19 °C) until drying for chemical analysis. Chemical compositions obtained from previous studies were used for ingredients that were difficult to sample, such as liquid whey, molasses and corn syrup, as well as feed additives with standard or constant chemical compositions, such as yeast cultures, ruminally inert fats and rumen buffers.

Information on farm, cow and pen characteristics, mixing equipment, feeding sequences and any anomalies were recorded for each dairy. The amount of TMR refused, and frequency of removal, was also recorded. A herd records file with milk production and composition data from the most recent DHIA milk test (*i.e.*, milk yield, true protein and fat proportions, somatic cell counts (SCC), days in milk (DIM) and lactation numbers), was downloaded prior to the start of the project, and again after the DHIA milk test results were entered.

Depending on the method used to monitor mixing and feeding, feed delivery records were collected for at least 5 days prior to the milk test from computerized programs or TMR mix sheets. Mixing information was used to calculate dry matter (DM) intake/pen.

2.3. Analytical methods

2.3.1. Feed preparation and assays

All TMR samples, silages and other wet ingredients were weighed before being dried at 55 °C for 48 h. All samples were removed and left to equilibrate for 24 h before they were bagged, weighed and tagged for analysis.

All samples were ground to pass a 1 mm screen using a model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ, USA). Feed and TMR samples were analyzed for DM, ash, neutral detergent fiber (aNDFom), acid detergent fiber (ADFom), lignin treated with sulphuric acid (lignin(sa)), starch, free sugars (soluble carbohydrates), CP, acid detergent insoluble CP (ADICP), minerals (TMR samples only), fat (EE), 30 h ruminal *in vitro* aNDF digestibility ($dNDF_{30}$) and soluble CP (SolCP) as described by Swanepoel et al. (2010).

2.3.2. Model evaluation

Once all cow and feed assay information was collected and tabulated, the nutrient profiles of the 16 rations were evaluated using the metabolic models Amino Cow (2007), CPM Dairy (2006) and Shield (Robinson, 2009). These models are all largely empirical, but with different AA levels assigned to feeds and microbial CP (MCP).

In all cases, cow information, calculated ingredient composition of the TMR and chemical composition of the feeds that were fed was entered into the models as required by model. All default feed components were used with the exception of feed DM, CP, ADFom, aNDFom and fat for Amino Cow, DM, CP, SolCP, ADICP, ADFom, aNDFom, lignin(sa), ash, fat, sugars and starch for CPM Dairy, and DM, OM, fat, CP, SolCP, ADICP, aNDFom and $dNDF_{30}$ for Shield.

3. Results

Results were divided into those that were measured and those that were model predicted. All feed and TMR samples collected and analyzed, as well as feeding and animal production data collected from the farms are measured values. Values and correlations drawn from models were predicted using the information gathered on the farms and thus are defined as predicted. The ration and model evaluation process determined relationships between variables to assess possible correlations among variables, even though this does not imply cause and effect.

3.1. Measured results

3.1.1. Ration evaluation

Where numerous samples of the same ingredient were collected, a subset of samples was pooled to obtain an average with a standard error (SE), except for corn DDG where all samples were assayed (Table 1). These average values were used in model evaluation. The composition of the ingredients was consistent among dairies, with only minor differences in a few nutrients and wet ingredients such as citrus pulp.

Forages were collected and assayed separately by dairy due to higher variation among them. Averages and SE of forages are in Table 2, but individual farm values were used in model evaluations. Alfalfa fresh chop was sampled at both farm visits, since it was cut daily leading to compositional differences among days. Alfalfa hay was divided into high or low quality (as defined by the dairy) when two sources were sampled, but there was little chemical difference between them. Forage composition was relatively consistent among dairies, with the possible exception of whole crop wheat silage.

Chemical composition of the two TMR samples from each dairy was analyzed separately and averaged (Table 3). The values for the 16 dairies, and minimum NRC (2001) recommendations where appropriate, are listed for comparison. Almost all major nutrient requirements were met by the 16 TMR, with no substantive nutrient undersupply on any dairy. There

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Table 1
Chemical analysis (+standard deviation if enough samples were collected) of commodity ingredients (g/100 g DM[a]) used in total mixed rations of the 16 dairies.

	n	DM[a]	OM[b]	CP[c]	ADICP[d]	SolCP[e]	$aNDF_{om}$[g]	$dNDF_{30}$[f]	ADF_{om}[h]	Lignin(sa)[i]	Starch	Fat	Sugars
Almond hulls	5[l]	93.00	92.20	5.69	25.66	40.36	34.72	31.67	28.50	10.99	1.72	2.45	17.81
		(1.344)[j]	(0.453)	(0.172)	(2.040)	(1.550)	(1.706)	(3.730)	(1.113)	(0.502)	(0.351)	(0.268)	(0.591)
Barley, rolled	1	91.00	97.19	12.19	2.56	22.29	21.50	55.70	7.80	2.00	50.70	1.74	1.30
Beet pulp shreds	2	94.10	93.93	9.52	3.94	42.97	32.25	86.36	20.15	0.83	6.43	0.74	18.80
Brandy pomace	1	30.94	89.96	10.75	37.79	30.80	39.70	31.16	43.90	21.70	0.50	2.50	0.20
Canola pellets	4[l]	91.15	91.59	42.72	6.09	33.40	24.38	45.40	18.55	7.63	2.83	3.95	6.53
		(0.380)	(0.197)	(0.324)	(1.560)	(0.510)	(1.186)	(2.000)	(1.154)	(1.014)	(0.782)	(0.108)	(0.312)
Carrot pulp	1	12.47	93.51	7.31	8.12	54.33	26.45	85.20	24.70	1.25	3.10	1.41	1.65
Citrus pulp	3	26.31	91.72	9.30	6.47	56.91	19.08	77.81	25.30	0.82	1.13	1.76	3.05
		(4.312)	(0.506)	(1.200)	(1.275)	(4.200)	(2.010)	(3.810)	(4.790)	(0.017)	(0.277)	(0.394)	(1.449)
Corn gluten feed	2	91.80	91.91	23.53	1.85	51.60	30.55	61.80	9.55	1.00	14.50	3.37	1.00
Corn grain, flaked	3[l]	85.53	98.75	8.68	0.00	25.50	8.27	66.60	3.10	0.40	73.07	2.59	0.50
		(0.384)	(0.062)	(0.554)	–	(3.080)	(0.233)	(2.690)	(0.153)	(0.100)	(2.335)	(0.704)	(0.153)
Cottonseed, whole linted	3[l]	93.17	95.69	21.34	7.39	23.00	43.17	9.30	33.83	9.80	0.50	20.18	0.67
		(1.040)	(0.047)	(0.740)	(0.997)	(0.010)	(2.282)	(0.750)	(1.633)	(0.600)	–	(1.196)	–
Cottonseed, ground pima	3	93.30	95.17	23.34	6.76	25.30	36.92	31.40	28.40	10.22	0.53	22.49	0.52
		(0.252)	(0.076)	(1.164)	(0.649)	(2.560)	(2.695)	(8.990)	(1.595)	(0.505)	(0.033)	(0.531)	(0.060)
Distillers grains, dried	6[l]	91.93	95.61	30.84	7.51	25.29	31.12	53.20	11.65	1.83	4.55	11.99	0.58
		(0.400)	(0.025)	(0.550)	(1.804)	(2.400)	(1.096)	(2.900)	(0.792)	(0.475)	(1.136)	(0.583)	(0.149)
Distillers grains, wet	3	32.99	96.78	36.03	14.10	29.55	30.80	54.10	16.83	2.47	3.03	10.37	0.20
		(0.708)	(0.162)	(0.883)	(1.132)	(3.370)	(0.777)	(2.930)	(0.977)	(0.203)	(0.318)	(0.183)	ND[k]
Linseed meal	1	91.80	92.03	43.70	2.79	28.23	ND	68.49	14.60	5.75	2.55	2.04	2.45
Linseed pellets	1	91.90	92.39	35.19	3.73	25.76	32.60	36.56	24.40	7.10	2.60	2.22	4.50
Raisin tailings	1	92.20	90.28	8.20	24.01	41.89	21.10	40.72	24.90	10.65	0.50	0.39	26.20
Soybean meal	3	91.23	92.46	51.10	0.32	21.25	8.50	69.60	5.10	0.20	5.17	0.58	9.37
		(0.260)	(0.128)	(0.749)	(0.317)	(0.050)	(0.702)	(0.240)	(0.379)	(0.058)	(0.491)	(0.106)	(0.617)
Wheat midds/millrun	3	90.58	94.57	18.48	2.28	38.50	37.33	45.90	11.48	2.78	24.13	3.22	2.60
		(0.466)	(0.081)	(0.361)	(0.050)	(3.000)	(1.203)	(1.900)	(0.433)	(0.165)	(1.866)	(0.387)	(0.158)

[a] Dry matter.
[b] Organic matter.
[c] Crude protein.
[d] Acid detergent insoluble CP, an estimate of indigestible CP (g/100 g of CP).
[e] Soluble CP (g/100 g of CP).
[f] 30 h ruminal *in vitro* amylase-treated neutral detergent fiber (aNDF) digestibility (g/100 g of aNDF).
[g] aNDF expressed exclusive of residual ash.
[h] Acid detergent fiber expressed exclusive of residual ash.
[i] Lignin assayed with sulphuric acid.
[j] Standard deviation.
[k] Not determined.
[l] 1 less sample for SolCP, $dNDF_{30}$ and fat.

Table 2
Chemical analysis (+standard deviation if enough samples were collected) of forages (g/100 g DM[a]) used in the total mixed rations of the 16 dairies.

	n	DM[a]	OM[b]	CP[c]	ADICP[d]	SolCP[e]	aNDFom[g]	$dNDF_{30}$[f]	ADFom[h]	Lignin(sa)[i]	Starch	Fat	Sugars
Alfalfa chop[k]	7	62.31	88.25	21.84	5.51	40.73	37.12	40.00	32.35	6.01	1.56	1.46	2.92
		(10.677)[j]	(0.456)	(0.836)	(0.412)	(1.780)	(0.910)	(1.590)	(0.690)	(0.152)	(0.095)	(0.084)	(0.465)
Alfalfa hay	11	92.25	89.12	21.06	5.31	35.81	35.86	37.82	29.44	5.48	1.87	1.52	4.24
		(0.264)	(0.365)	(0.764)	(0.243)	(0.670)	(1.230)	(1.400)	(1.200)	(0.324)	(0.147)	(0.096)	(0.268)
Alfalfa hay HQ[l]	3	92.37	89.79	21.22	5.74	36.15	36.53	31.92	29.37	5.57	2.17	1.55	4.10
		(0.384)	(0.632)	(1.153)	(0.903)	–	(2.230)	–	(1.157)	(0.176)	(0.367)	(0.090)	(0.404)
Alfalfa hay LQ[l]	3	92.27	86.84	22.75	6.04	37.61	35.60	34.47	29.67	5.53	1.20	1.22	2.97
		(0.371)	(0.389)	(0.729)	(1.049)	–	(1.660)	–	(1.580)	(0.406)	(0.265)	–	(0.578)
Alfalfa silage	4	43.33	86.16	25.49	5.60	70.83	30.88	43.28	26.88	5.40	<0.50	3.01	0.48
		(5.494)	(0.814)	(1.297)	(0.171)	(4.420)	(0.600)	(2.490)	(0.940)	(0.100)	–	(0.430)	(0.293)
Corn earlage	1	60.08	97.24	8.35	37.43	66.15	21.15	64.30	10.60	1.00	53.10	3.09	0.90
Corn silage	15	31.81	92.85	7.91	8.81	67.30	42.45	51.02	26.95	2.94	24.66	3.17	<0.20
		(0.718)	(0.226)	(0.173)	(0.440)	(1.120)	(0.890)	(1.080)	(0.570)	(0.131)	(0.903)	(0.171)	–
Oat straw	1	92.50	91.70	8.19	7.63	34.42	56.50	57.98	34.10	3.60	9.20	1.52	5.60
Rice straw	1	93.00	84.67	4.40	29.83	29.55	63.70	46.52	38.50	4.40	3.00	2.02	2.90
Wheat silage	5	33.66	88.14	10.60	9.67	74.39	48.22	51.60	30.84	4.08	9.98	2.62	2.37
		(2.095)	(0.892)	(0.885)	(1.106)	(1.270)	(1.901)	(2.030)	(1.225)	(0.166)	(2.303)	(0.234)	–
Wheat straw	2	92.75	90.55	8.51	9.92	34.68	57.05	45.73	34.75	4.10	9.90	0.99	4.55

[a] Dry matter.
[b] Organic matter.
[c] Crude protein.
[d] Acid detergent insoluble CP, an estimate of indigestible CP (g/100 g of CP).
[e] Soluble CP (g/100 g of CP).
[f] 30 h ruminal *in vitro* amylase-treated neutral detergent fiber (aNDF) digestibility (g/100 g of aNDF).
[g] aNDF expressed exclusive of residual ash.
[h] Acid detergent fiber expressed exclusive of residual ash.
[i] Lignin assayed with sulphuric acid.
[j] Standard deviation.
[k] Alfalfa chop were collected twice at 2–4-day intervals. Analyzed component values were averaged.
[l] High (HQ) and Low (LQ) quality alfalfa as specified by each farm.

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Table 3
Chemical analysis (g/100 g dry matter) of high group total mixed rations sampled at the 16 dairies.

Farm number	1	2	3	4	5	6	7[a]	8[a]	9	10	11	12	13	14[a]	15	16	Avg	NRC[b]
Dry matter	55.20	61.63	55.51	57.20	61.65	59.60	63.10	59.29	62.22	52.00	53.95	59.79	45.20	63.42	61.62	58.53	58.12	
OM[c]	92.40	91.89	90.87	90.99	92.54	92.17	93.15	90.59	91.59	91.40	91.27	90.74	90.47	92.01	92.23	92.30	91.66	
Crude protein	17.31	18.16	17.47	16.28	16.00	15.88	17.13	17.38	17.98	16.84	18.50	17.31	16.47	17.53	16.81	18.88	17.25	16.0–16.7
ADICP[d]	5.44	5.88	5.72	7.29	6.45	7.30	6.38	6.30	4.45	5.57	7.09	5.76	7.63	6.61	8.37	8.40	6.61	
SolCP[e]	39.42	38.39	37.31	37.92	35.70	39.68	34.82	40.39	40.92	39.16	41.87	34.53	39.50	34.77	40.42	36.86	38.23	
aNDFom[f]	27.05	31.40	27.70	28.95	31.90	28.80	31.25	29.90	30.65	29.05	32.25	26.25	32.63	30.65	29.85	31.65	30.00	25–33
$dNDF_{30}$[g]	47.72	52.40	44.26	46.49	44.11	41.18	53.75	41.27	46.85	46.87	45.50	46.54	48.03	46.74	43.33	47.25	46.39	
ADFom[h]	18.30	20.00	19.10	21.25	20.75	19.60	19.65	20.80	19.30	20.15	20.70	18.35	22.10	20.35	20.60	21.70	20.17	17–21
Lignin(sa)[i]	3.50	4.80	2.75	4.95	4.85	4.90	4.40	4.75	3.43	4.25	4.60	3.40	4.40	4.80	5.90	4.35	4.38	
Starch	15.90	15.35	22.10	19.50	18.25	16.30	19.40	20.40	20.63	20.60	14.30	20.90	10.65	17.35	19.20	18.00	18.05	
Fat	5.47	5.39	4.68	4.84	5.14	5.19	5.95	5.04	5.09	5.09	7.03	7.06	6.20	5.84	5.30	7.62	5.68	
Sugars	4.90	3.25	2.95	3.25	4.55	4.90	3.55	3.25	2.03	1.60	2.65	1.55	3.18	3.35	4.15	2.50	3.23	
NE_L (MJ/kg)[j]	7.50	7.35	7.07	7.09	6.98	7.04	7.60	6.80	7.11	7.19	7.10	7.56	7.03	7.21	7.05	7.37	7.19	6.74
Ca	0.96	0.82	1.03	0.91	0.79	0.72	0.64	1.04	0.76	0.94	0.85	1.15	0.85	0.83	0.88	0.93	0.88	0.60–0.67
P	0.43	0.53	0.36	0.42	0.44	0.48	0.44	0.50	0.43	0.42	0.50	0.50	0.49	0.46	0.42	0.46	0.46	0.36–0.38
K	1.48	1.55	1.73	1.74	1.60	1.84	1.53	2.06	1.63	1.77	1.78	1.39	1.65	1.64	1.65	1.55	1.66	1.06–1.07
Mg	0.35	0.29	0.42	0.33	0.36	0.30	0.27	0.33	0.40	0.37	0.32	0.41	0.28	0.26	0.39	0.29	0.34	0.20
S	0.25	0.35	0.25	0.27	0.27	0.22	0.29	0.27	0.34	0.24	0.31	0.26	0.30	0.29	0.28	0.31	0.28	0.20
Na	0.35	0.36	0.43	0.52	0.26	0.38	0.21	0.41	0.32	0.50	0.58	0.51	0.58	0.38	0.30	0.38	0.40	0.22
Cl	0.57	0.54	0.65	0.73	0.59	0.58	0.48	0.83	0.64	0.46	0.60	0.37	0.77	0.42	0.41	0.50	0.57	0.28–0.29
ppm DM																		
Zn	59.50	63.00	78.50	103.5	73.50	43.00	52.50	103.0	71.50	67.50	74.50	110.0	84.50	57.00	78.00	72.50	74.50	52–55
Mn	40.50	46.00	77.50	69.00	69.00	32.00	38.50	95.50	62.75	58.50	75.50	73.50	54.75	55.00	81.00	58.00	61.69	13
Fe	282.0	313.5	410.0	272.5	164.5	304.5	188.5	286.0	385.3	193.5	269.0	506.5	295.8	260.0	170.5	266.0	285.5	17–18
Cu	10.30	21.35	18.15	24.30	12.55	7.95	6.80	25.65	12.15	23.15	13.80	22.65	14.90	12.80	12.40	10.00	15.56	11
Co	0.20	0.50	1.30	1.20	0.65	0.20	0.20	1.05	1.20	0.30	0.50	0.50	0.30	1.00	0.45	1.25	0.68	0.11
Se	0.35	0.44	0.39	0.46	0.52	0.25	0.25	0.60	0.44	0.22	0.47	0.60	0.63	0.44	0.53	0.34	0.43	0.30

[a] Values only represent one total mixed ration sample.
[b] NRC Values for 45 to 50 kg/day milk production (provide recommendations for NDF and ADF, not NDFom and ADFom).
[c] Organic matter.
[d] Acid detergent insoluble crude protein (CP), an estimate of indigestible CP (g/100 g of CP).
[e] Soluble CP (g/100 g of CP).
[f] Amylase-treated neutral detergent fiber (aNDF) expressed exclusive of residual ash.
[g] 30 h ruminal *in vitro* amylase-treated neutral detergent fiber (aNDF) digestibility (g/100 g of aNDF).
[h] Acid detergent fiber expressed exclusive of residual ash.
[i] Lignin assayed with sulphuric acid.
[j] Net energy available for lactation, calculated from equations utilizing chemical assays and *in vitro* determinations as described by Robinson et al. (2004).

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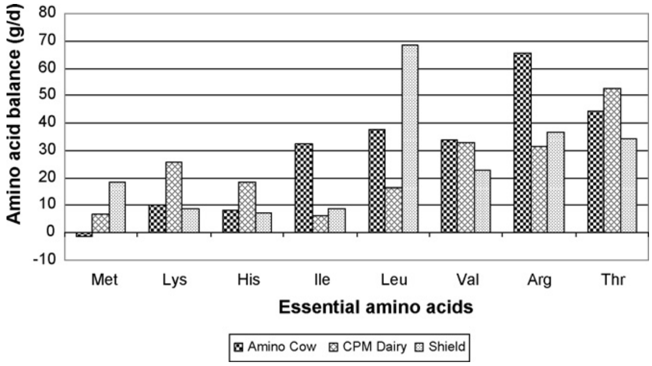

Fig. 1. Balances of average metabolizable amino acid (difference between estimated amino acid requirement and delivery) for the 16 California dairy rations as predicted by Amino Cow, CPM Dairy and Shield.

was also high consistency among the dairies in the chemical composition of the TMR and its estimated net energy for lactation.

The ingredient profiles (as g/kg DM) of the TMR mixed for the specified pen on each of the 16 dairies (Table 4) was obtained using the on-farm computerized feed programs, which provided the actual weights of each ingredient added to the TMR during the week of the survey, or TMR mix sheets which represent the theoretical TMR. Weights were converted to g/kg DM using the analyzed DM for each ingredient. In some cases, as in Dairy 2, accurate information on the composition of added milk cow minerals were lacking. Some ingredients were used in more than 0.8 of dairies while a few ingredients were only found on one or two. Corn products (mainly corn grain, DDG and corn silage with corn gluten feed in two and corn earlage on one of the dairies) make up 410 g/kg of the TMR DM on average, ranging from 310 to 550.

3.1.2. *Description of dairies*

The 16 dairies were characterized in terms of general farm management, milk production and composition, as well as intake levels and general characteristics of the cows in the specified high group (*i.e.*, lactating cows not yet confirmed to be in calf) pen (Table 5). Milk production levels were used to assign dairy numbers starting with the lowest production of 32.8 kg/d in Dairy 1, increasing to 51.3 kg/d in Dairy 16. Milk yield was dissimilar among dairies, probably because they included free stall and dry lot facilities, with 800–5000 lactating cows/dairy, milking frequencies of 2 or 3 times a day that occurred in older 'flat barns' or modern double 20–40 parallel or herring bone milking parlours.

Average DIM were calculated together with the 10th and 90th percentiles (*i.e.*, 10% less than highest and 10% higher than the lowest DIM) to exclude extreme values and provide a better representation of DIM profiles of the cows in the pens. The number of cows in the high group pen on each dairy represents only one pen, except where TMR from one load was divided between two very similar pens and uncertainties in the weight of TMR fed to each pen necessitated combination of those pens for a more accurate intake calculation.

The DM intake levels were calculated from the amount of TMR fed, estimated or calculated refusals (orts) and cow numbers, together with analyzed TMR DM values, giving average DM intakes/cow/d. All other information was obtained using the on-farm dairy herd management programs and DHIA records.

3.2. *Predicted results—model evaluation*

From model evaluations, some predictions common to the models were tabulated for each dairy (Table 6). These included predicted DM intake, estimated metabolizable protein (MP) delivery and balance (referred to in Shield as absorbable protein 'AP'), as well as the estimated delivery (g/d) and balance of metabolizable essential AA (EAA).

CPM Dairy estimated only 0.88 of measured DM intake while Amino Cow estimated 0.96 and Shield 1.02. Average estimated delivery of MP was essentially the same between CPM Dairy and Shield (2960 *versus* 2928 g/d) while Amino Cow estimated only 2594 g/d. The estimated MP balances were 1.22, 1.04 and 0.99 of requirements for Amino Cow, CPM Dairy and Shield, respectively. However there was substantial variation among dairies within model. The ratio between lysine and methionine was above 3 for Amino Cow and CPM Dairy (3.29 and 3.24) while Shield predicted only 2.61.

The summary of AA balances (Fig. 1) shows major differences among model predictions. The average balance of metabolizable methionine ranged from −1 (Amino Cow) to 18 g/d (Shield), while lysine ranged from 9 (Shield) to 26 g/d (CPM Dairy). The histidine balance was higher for CPM Dairy (18 g/d) *versus* Amino Cow (8 g/d) and Shield (7 g/d). The isoleucine balance was much higher for Amino Cow (32 g/d) *versus* CPM Dairy (6 g/d) and Shield (9 g/d). Leucine balances varied among models from a low of 16 g/d (CPM Dairy) to 37 g/d (Amino Cow) and 69 g/d (Shield). The valine balance was lower for Shield (23 g/d)

Table 4
Ingredient profiles (g/100 g dry matter) of high group total mixed rations sampled at the 16 dairies.

Farm number	1	2[a]	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Forages:																
Alfalfa chop					9.73			24.17		20.52	2.10		3.76	5.72	20.48	
Alfalfa hay	22.62	16.85	19.27	18.90	8.18	21.75			23.82	5.13	7.67	20.60	10.31	20.10		14.38
Alfalfa silage		7.24	4.69								3.93					7.76
Corn earlage									16.5							
Corn silage	16.31	19.56	23.14		18.39	13.43	12.04	21.79	23.26	23.80	14.77	14.85	11.02	7.13	12.92	21.84
Oat straw/hay									1.65			1.59				
Rice straw													1.85			
Wheat silage				14.81			14.65				5.01		12.43	8.31		
Wheat straw/hay					1.52										0.50	
Plant products, grains and seeds																
Almond hulls	7.24	10.90	2.80	8.70	13.39	22.01	4.94	6.99			11.34		3.84	2.56	15.26	7.85
Barley, rolled							5.43									
Beet pulp shreds							7.90							3.62		
Brandy pomace													1.23			
Canola pellets		6.10		4.54			7.42				3.78		8.22	7.46	8.30	7.94
Carrot pulp				4.66												
Citrus pulp	3.37											9.27			3.01	
Corn grain, flaked	15.02	10.03	18.43	24.77	17.64	15.18	18.69	15.70	8.40	19.81	16.68	26.50	8.49	17.90	17.87	15.33
Corn grain, ground			1.64													
Corn gluten feed		6.12											3.65			
Corn gluten meal			0.34													
Cottonseed, whole linted	4.50		8.48	6.52	6.25	6.62		6.51	6.67	7.75	8.07	12.05	6.87		6.20	9.60
Cottonseed, ground pima		6.24					11.39							10.06		
Cottonseed, meal										6.27						
Distillers grains, dry	8.97	9.22	3.50	7.35	6.77	8.53	7.12	4.98	6.58	5.95	3.17	4.76	2.87	5.68		10.30
Distillers grains, wet											5.50		6.23		5.60	
Linseed, meal									7.79							
Linseed, pellets					6.76											
Raisin tailings													2.76			
Rice bran	2.64															
Soy hulls			1.69													
Soybean, meal	6.17		6.63	5.47		6.71		6.70				5.51				
Soyplus[b]			1.09					0.41								
Wheat midds/millrun	5.28				8.15		7.61	4.27			7.65			8.23	6.00	
Miscellaneous:																
Almond shells																0.23
Blood meal			0.72													
Corn/distillers syrup							0.88							0.69		
Fat (animal)	0.97												0.49			
Fat (liquid)								0.69								
Fat (rumen inert)			1.09	1.28			1.41	0.36	0.77	1.81			3.93	1.01	0.63	2.26
Fish meal								0.40								
Generator D[c]			0.0004								0.02					
Millrun+tallow mix											3.68					
Mineral mixes	0.69	7.73[d]	2.19	1.51	1.78	2.10	0.52	0.35	0.96	2.19	1.48	4.44[d]	2.13	1.53	1.87	0.58
Molasses			0.97		1.42			3.45	2.33						1.06	
Prolac[e]									0.69							
Salt																0.57

Table 4 (*Continued*)

Farm number	1	2[a]	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sodium Bicarbonate	0.49		0.74	0.99		0.73		0.45	0.59	0.92	0.77		0.90			0.57
Urea	0.29		0.14	0.46		0.60		0.37		0.56	0.33	0.25	0.26		0.28	0.39
Water			0.02	0.03	0.01											
WCS replacer[f]											1.84					
Whey (liquid)	5.13		2.38			2.34		2.31		5.30	2.22		8.76			
Yeast	0.30											0.19				0.40
Total amount of corn products used	40.30	44.93	47.05	32.12	42.80	37.14	38.73	42.47	54.74	49.56	40.12	46.11	32.26	31.40	36.39	47.47

[a] Accurate information on the composition of the milk cow mineral was not provided by the dairy.
[b] Heat-processed, all-natural soybean meal, deliver 60% rumen bypass protein. SoyPLUS®, West Central, Ralston, IA, USA.
[c] Direct fed microbial. Bio-Vet Inc., Blue Mounds, WI, USA.
[d] Inclusion level of top mix/premix consisting of a mineral mix and other ingredients.
[e] Probiotic containing the lactic acid strains L. reuteri and L. acido. Vitacel® Prolac, J. Rettenmaier & SöhneGmbH + Co. KG, Rosenberg, Germany.
[f] Whole cottonseed replacer, Imperial Western Products, Inc., CA, USA.

Table 5
Description of the 16 dairies, cows and pens designated by the dairy as one of their high group pens[a].

Farm number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
General information																
Total lactating cows	1000	1143	3000	1192	1809	2772	824	5000	1200	2648	2200	4100	5000	932	4400	1378
Milkings/day	2	2	2	2	2	3	2	2	3	2	2	3	3	2	2	3
Animals																
Cows in high group pen[b]	149	123	170	190	189	145	265[c]	408	158	513[c]	191	264	364	223[c]	587[c]	167
Days in milk																
10th %	84	46	57	99	29	22	112	36	89	94	63	91	31	35	37	42
Average	221	97	87	132	86	87	199	108	210	157	111	160	92	133	124	88
90th %	345	141	119	170	129	139	291	170	321	236	164	226	156	218	218	134
Parity (%)																
1	5	22	0	0	15	1	0	2	1	2	0	4	1	0	0	1
2	62	53	49	30	58	52	39	11	59	47	44	46	48	16	0	37
>3	33	25	51	70	27	47	61	87	40	51	56	50	51	84	100	62
Parity (maximum)	6	8	7	9	5	8	6	10	5	8	9	8	6	9	10	9
Production																
Milk yield (kg/d)	32.8	37.9	40.3	40.9	41.2	41.4	41.7	42.8	43.3	45.2	45.4	46.6	46.7	47.7	48.5	51.3
True prot%	3.23	2.91	2.77	2.88	2.93	2.87	3.13	2.81	3.00	2.72	2.84	2.95	2.87	2.92	3.01	2.73
Fat %	3.32	3.49	3.19	3.67	3.14	3.49	3.54	3.08	3.68	3.04	3.32	3.54	3.19	3.49	3.45	3.79
SCC (.000)[d]	739	270	75	187	70	122	262	264	219	163	132	95	375	438	416	364
Intakes																
As fed (kg/d)	43.9	34.7	48.3	43.5	46.2	37.8	45.0	44.9	40.2	52.5	48.2	45.8	53.0	41.1	48.8	49.9
DM basis (kg/d)	24.2	21.4	26.8	24.9	28.5	22.5	28.4	26.6	25.0	27.3	26.9	27.4	24.0	26.0	30.1	29.2
Total mixed ration DM %	55.2	61.6	55.5	57.2	61.7	59.6	63.1	59.3	62.2	52.0	54.0	59.8	45.2	63.4	61.6	58.5

[a] High group pen cows are defined as cows that are lactating but have not yet been confirmed to be in calf.
[b] Number of cows in the single high group pen used for the survey.
[c] Number of cows in two, very similar pens, fed from the same truck, combined.
[d] Somatic cell count.

Table 6
Protein and amino acid status of the high group rations according to 'Amino Cow', 'CPM Dairy' and 'Shield'.

Farm number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Ave
DM[a] intake (kg/d)																	
Measured	24.2	21.4	26.8	24.9	28.5	22.5	28.4	26.6	25.0	27.3	24.5	27.4	24.0	26.0	30.1	29.2	26.1
Predicted																	
Amino Cow	22.2	23.8	23.6	25.0	23.7	24.4	25.0	24.4	25.7	25.0	25.6	26.4	25.4	26.6	26.7	27.9	25.1
CPM Dairy	20.1	21.6	21.2	22.9	21.8	22.0	22.4	22.2	23.1	22.4	23.4	24.2	23.4	24.3	24.5	25.8	22.8
Shield	22.7	25.9	28.5	30.5	24.9	25.4	23.1	25.9	26.7	27.9	27.4	24.5	27.2	28.3	27.0	28.1	26.5
MP Delivery (g/d) [b]																	
Amino Cow	2447	2261	2769	2516	2592	2236	2704	2740	2622	2764	2537	2560	2317	2631	2858	2948	2594
CPM Dairy	2805	2389	3212	2853	3143	2527	3246	3119	2712	3059	2903	3207	2512	3045	3422	3200	2960
Shield	2844	2545	2884	2566	3104	2495	3130	3026	2886	3043	2855	3160	2587	3140	3279	3299	2928
MP bal (g/d) [c]																	
Amino Cow	727	457	974	581	644	279	616	782	521	769	470	376	129	399	523	703	559
CPM Dairy	433	−7	608	195	343	−135	277	393	−165	221	−9	228	−419	21	122	20	133
Shield	148	−193	398	297	306	−284	−228	109	−227	169	−200	−95	−653	−275	0	92	−40
mMet (g)[d]																	
Amino Cow	51	47	57	53	53	46	56	58	55	58	53	52	49	55	60	61	54
CPM Dairy	57	47	62	57	65	51	65	64	54	57	58	62	51	59	69	60	59
Shield	61	56	58	55	69	53	68	68	66	67	64	69	58	70	74	75	64
mMet (g/100 g MP)[e]																	
Amino Cow	2.08	2.09	2.06	2.11	2.05	2.05	2.09	2.13	2.09	2.10	2.10	2.04	2.10	2.10	2.11	2.08	2.09
CPM Dairy	2.05	1.96	1.92	1.99	2.07	2.03	1.99	2.04	2.00	1.88	2.01	1.93	2.03	1.93	2.01	1.88	1.98
Shield	2.13	2.21	2.01	2.24	2.23	2.14	2.19	2.24	2.30	2.20	2.25	2.17	2.23	2.23	2.24	2.26	2.20
mLys (g)																	
Amino Cow	171	153	200	177	168	155	180	197	177	191	170	172	158	181	197	195	178
CPM Dairy	184	148	214	185	199	167	200	209	174	191	183	205	161	195	224	197	190
Shield	167	148	174	160	167	146	172	179	164	171	160	176	147	184	183	176	167
mLys (g/100 g MP)																	
Amino Cow	7.00	6.78	7.21	7.02	6.48	6.95	6.64	7.20	6.74	6.90	6.72	6.71	6.80	6.88	6.90	6.62	6.85
CPM Dairy	6.56	6.20	6.67	6.48	6.33	6.61	6.16	6.68	6.43	6.25	6.29	6.38	6.40	6.42	6.54	6.16	6.41
Shield	5.88	5.81	6.05	6.22	5.37	5.86	5.50	5.92	5.68	5.63	5.59	5.57	5.66	5.87	5.57	5.35	5.72
Lys:Met																	
Amino Cow	3.35	3.26	3.51	3.34	3.17	3.37	3.21	3.40	3.22	3.29	3.21	3.31	3.22	3.29	3.28	3.20	3.29
CPM Dairy	3.20	3.16	3.47	3.26	3.06	3.26	3.09	3.27	3.21	3.33	3.13	3.30	3.15	3.33	3.26	3.28	3.24
Shield	2.76	2.63	3.01	2.90	2.41	2.74	2.51	2.64	2.48	2.56	2.49	2.57	2.54	2.63	2.49	2.36	2.61
mHis (g/d)																	
Amino Cow	61	56	73	63	63	55	68	68	64	69	63	64	57	66	71	73	65
CPM Dairy	72	61	90	75	80	65	87	81	70	80	76	82	67	83	93	85	78
Shield	57	50	67	52	59	49	64	61	54	64	56	63	51	62	66	66	59
mIle (g/d)																	
Amino Cow	137	124	153	141	138	124	143	156	144	153	138	138	128	143	157	158	142
CPM Dairy	142	120	158	143	161	129	156	159	142	154	145	161	128	155	175	158	149
Shield	117	104	112	111	116	102	123	121	112	121	114	123	108	133	132	130	117
mLeu (g/d)																	
Amino Cow	227	207	262	233	230	205	240	252	240	253	232	232	215	235	260	268	237
CPM Dairy	224	192	269	233	246	203	252	250	214	242	230	257	206	241	271	256	237
Shield	248	216	256	214	260	216	267	259	232	259	251	275	232	269	284	286	252
mVal (g/d)																	
Amino Cow	154	141	177	157	158	139	165	173	165	173	157	156	146	164	178	181	162
CPM Dairy	160	138	189	164	183	146	184	179	163	178	168	180	148	180	201	188	172
Shield	142	133	143	133	148	124	160	149	139	154	147	155	132	164	167	165	147

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Table 6 (*Continued*)

Farm number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Ave
mArg (g/d)																	
Amino Cow	134	119	156	139	144	122	151	154	148	162	139	146	124	148	155	157	144
CPM Dairy	181	146	207	181	206	164	207	204	184	204	183	207	158	198	218	200	191
Shield	141	126	148	131	149	120	151	154	142	168	137	154	122	157	160	152	145
mThr (g/d)																	
Amino Cow	134	123	152	138	137	122	143	152	142	151	137	136	126	143	156	157	141
CPM Dairy	138	113	155	139	151	125	151	154	132	145	138	154	121	147	167	151	143
Shield	135	121	131	127	140	118	143	141	136	138	134	144	123	152	154	152	137

[a] Dry matter.
[b] Metabolizable protein.
[c] MP balance, the difference between estimated MP requirement and delivery.
[d] Estimated delivery (g/d) of amino acids to the small intestine.
[e] Metabolizable amino acids expressed as a percentage of metabolizable crude protein.

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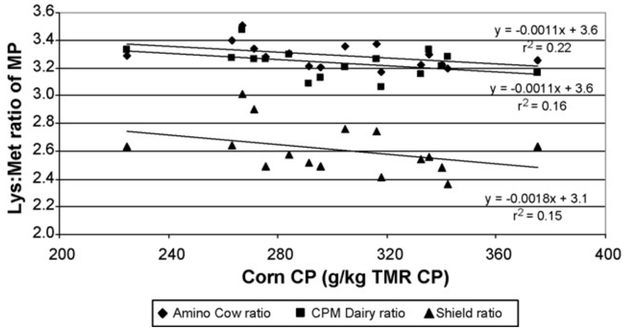

Fig. 2. The effect of corn crude protein in the total mixed ration on the ratio of Lys to Met in metabolizable protein predicted by Amino Cow, CPM Dairy and Shield.

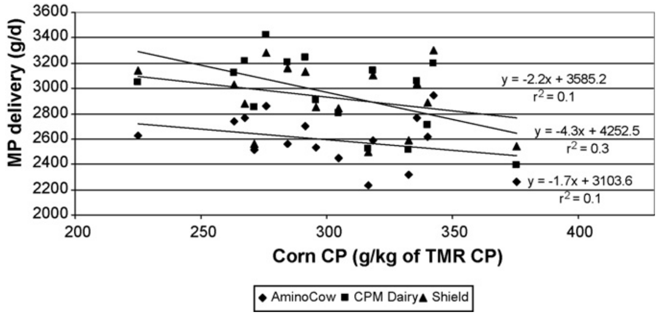

Fig. 3. The effect of corn crude protein in the total mixed ration on metabolizable protein delivery to the intestine as predicted by Amino Cow, CPM Dairy and Shield.

versus Amino Cow (33 g/d) and CPM Dairy (32 g/d). The arginine balance for Amino Cow was 65 g/d, which was much higher than the 38 and 31 g/d for Shield and CPM Dairy. Threonine balances differed among models with CPM Dairy, Amino Cow and Shield predicting 52, 44 and 34 g/d.

4. Discussion

4.1. Effect of increased contribution of corn crude protein to total TMR CP on milk production

Even though most of the rations had a CP level slightly higher than NRC requirements (Table 3) with 200–400 g/kg of total TMR CP coming from corn products, there was no negative effect of increased levels of corn products *per se* on milk production, protein or fat content, suggesting that even though corn proteins made up a large proportion of total CP consumed, the unbalanced AA profile was either offset by inclusion of other, possibly complementary, CP sources such as canola meal, whole cottonseed, soybean meal and small amounts of animal protein sources (*i.e.*, blood meal and fish meal) or because CP levels of some rations were relatively high (up to 188 g/kg DM).

4.2. Model evaluation

Metabolic models were used to provide estimates of AA requirements and availability as there are no other accepted and published AA evaluation models providing adequate information on this set of feed ingredients that could be used to evaluate these performance results in quantitative terms.

4.2.1. Effect of increased contribution of corn CP to total TMR CP on amino acid profile of metabolizable protein

Even though the models did not agree on the AA profiles of protein reaching the intestine, their predictions regarding the effect of increased corn levels in the diet on these AA profiles were very consistent. As might be expected due to the low level of lysine in corn proteins, all models predicted that the lysine to methionine ratio in MP decreased as more corn protein was added to the TMR (Fig. 2), even though the ratio itself differed sharply among models.

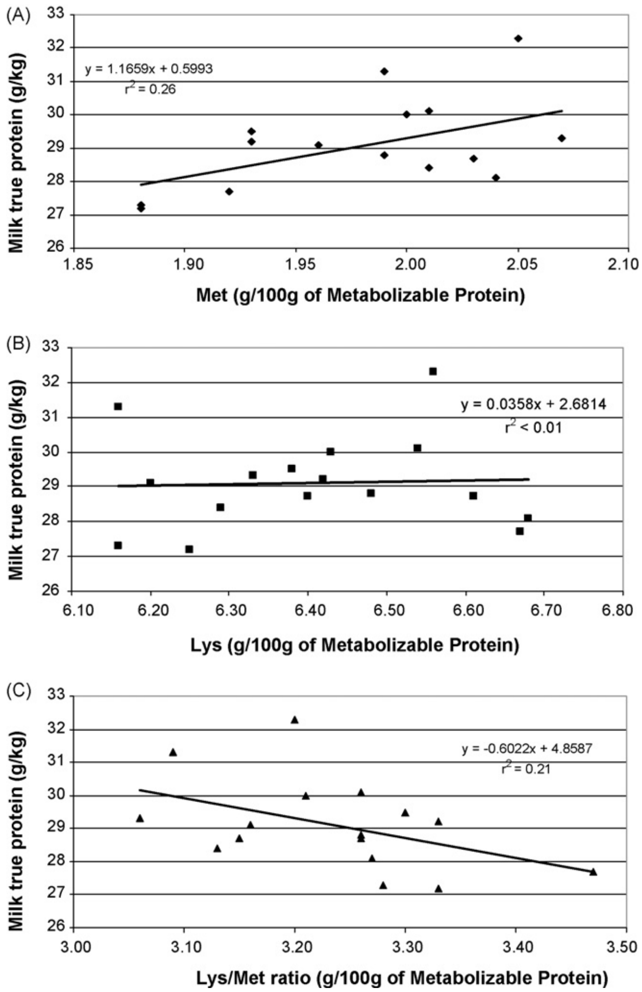

Fig. 4. The response of milk true protein proportion (g/kg) to changes in proportions of (A) Met, (B) Lys and (C) the Lys to Met ratio in metabolizable protein as predicted by CPM Dairy.

The models also suggested a decrease in MP delivery with increased contribution of corn CP to total TMR CP (Fig. 3) but none predicted any change in the proportion of methionine or lysine in MP when corn CP in the TMR increased (Table 6). Most corn proteins are higher in rumen degradable CP (∼550 g/kg CP) than rumen undegradable CP, which could explain the predicted decrease of MP delivery when corn CP levels in the ration increased. That the AA levels in MP did not change, however, could be due to the increased proportional contribution of MCP (high in lysine) to total MP, delivering a much better balance of AA to the intestine. Increased MCP production could be due to better energy and N synchronization in high corn rations, therefore increasing the efficiency of microbial growth.

4.2.2. Effect of increased contribution of corn CP to total TMR CP on milk composition

Corn CP levels in the TMR seemed to cause a change in the predicted ratio of lysine to methionine reaching the intestine (Fig. 2) which, in turn, might have impacted milk composition. However neither the proportion, nor the ratio, of lysine and methionine in MP had any affect on either milk fat or milk true protein proportion. CPM Dairy was the only model that predicted, albeit to a very small extent ($r^2 = 0.21$), an increase in milk protein level with a decrease in lysine to methionine ratio (Fig. 4), but this was due to increased delivery of methionine ($r^2 = 0.26$), not a decrease in lysine ($r^2 < 0.01$), suggesting that the decline in lysine delivery to the intestine due to high inclusion levels of corn products was not large enough to have impacted milk protein, but that the higher methionine content of corn products increased methionine delivery, with a resulting increase in milk protein proportion.

The predicted increase in methionine contribution to MP (*i.e.*, 18.8–20.7 g/kg; Table 6) only yielded a small increase in milk true protein. CPM Dairy was the only model to predict a correlation between AA and milk components (*i.e.*, milk true protein), and Shield was the only one to predict a correlation between AA and milk yield (Fig. 5). Contrary to expectations with decreased lysine (NRC, 2001), Shield predicted milk yield to increase when the ratio of lysine to methionine decreased, due to higher methionine and lower lysine proportions in MP (Fig. 6), which corresponds with AA levels in corn products.

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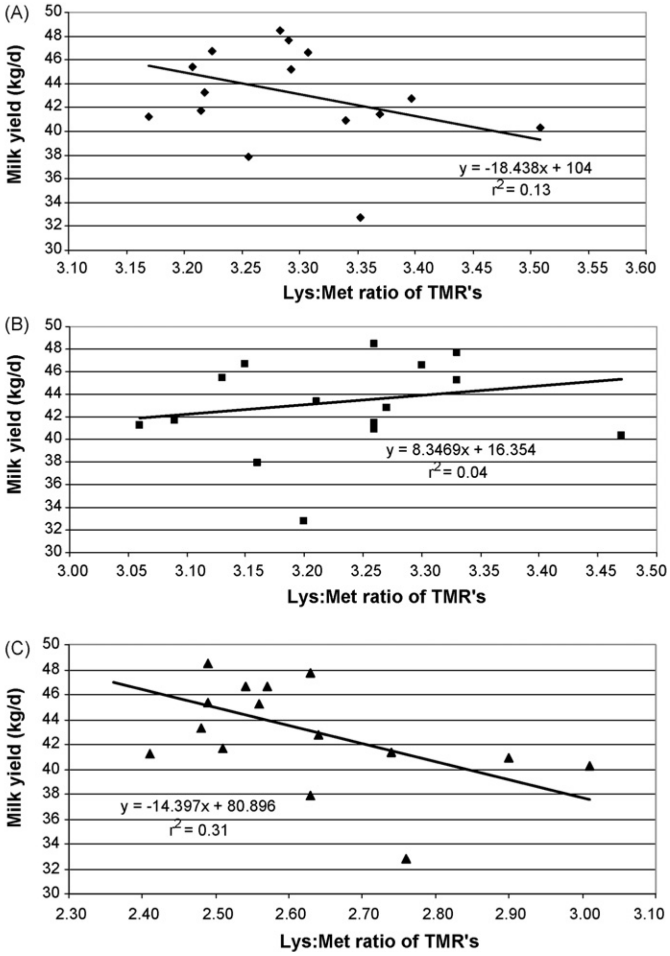

Fig. 5. The response of milk yield (kg/d) to changes in the Lys to Met ratio as predicted by (A) Amino Cow, (B) CPM Dairy and (C) Shield.

The yield increase of 18.5 kg/d, due to changes in the ratio of lysine to methionine (from 3.01 to 2.36) predicted by Shield, is much more substantive than the protein increase predicted by CPM Dairy. The possibility of increased dietary corn levels impacting milk yield therefore seems higher than for milk components.

Similar comparisons were made between other EAA and milk production (not shown), but no relationship was predicted by Amino Cow, CPM Dairy or Shield.

4.2.3. Predicted amino acid packages

The sequence of AA limitation (Table 7) among dairies was the same within Amino Cow (*i.e.*, methionine, lysine, histidine, leucine, valine, isoleucine) and very similar within Shield (*i.e.*, lysine, isoleucine, histidine, valine, arginine). In contrast, the sequence varied somewhat within CPM Dairy, although isoleucine and leucine were always (with one exception) either first or second limiting, methionine and lysine were always third or fourth limiting followed by arginine, valine and histidine.

Based upon the evaluation of each ration by each model, average AA supplementation packages were calculated to bring model estimated AA deliveries to a minimum of 1.10, 1.20 and 1.30 of model estimated requirements (Table 8). Due to differences among models in predicted AA limitation sequences, the calculated AA supplementation packages varied sharply by model. In general, Amino Cow emphasized methionine and lysine as being most limiting. CPM Dairy emphasized isoleucine and leucine, whereas Shield emphasized lysine and isoleucine. Only threonine appeared in no AA package, although arginine only appeared in CPM Dairy, and at low levels. Except at 1.10, where the sizes of the AA packages were low (*i.e.*, 9–14 g/cow/d), CPM Dairy required AA package sizes that were 1.5 (at 1.20) to 0.7 (at 1.30) the size of those of Amino Cow and Shield (Table 8). This reflects the higher predicted animal requirements (g/d) for AA according to CPM Dairy.

Variation in predicted AA limitation sequences among models are likely due to differences in assigned AA levels of feed and MCP, and AA 'transfer coefficients' on which each model based prediction for efficiency of AA digestion, absorption and utilization. Likewise, predicted AA supply to the intestinal absorptive site depends on the default chemical composition of

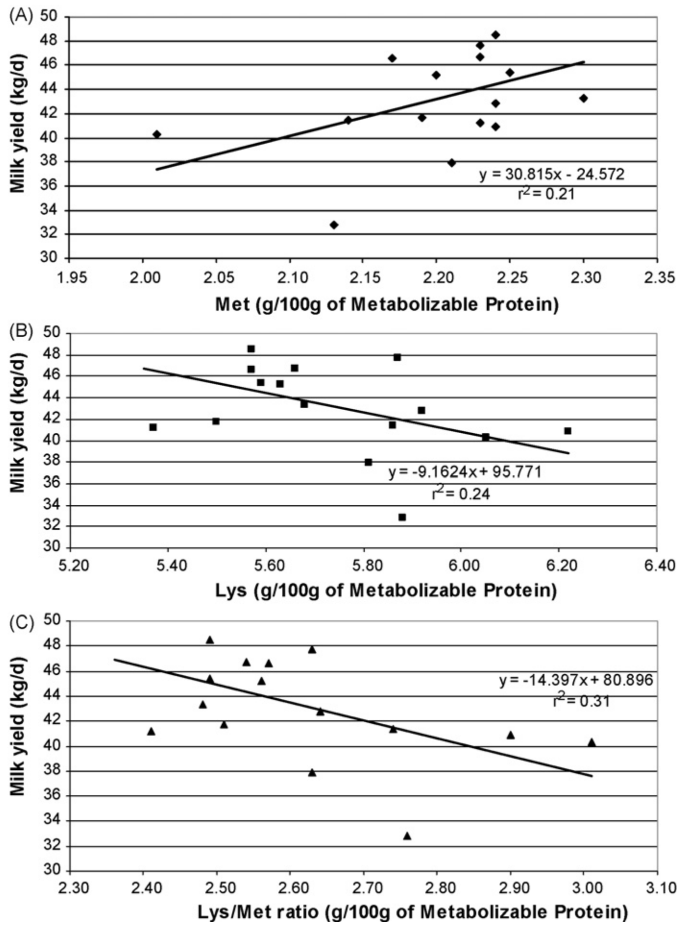

Fig. 6. The response of milk yield (kg/d) to changes in proportions of (A) Met, (B) Lys and (C) the Lys to Met ratio in metabolizable protein predicted by Shield.

Table 7
The sequence of amino acid limitation according to 'Amino Cow', 'CPM Dairy' and 'Shield'[a].

Farm number	Seq[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Amino Cow	1	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met	Met
	2		Lys		Lys	Lys	Lys	Lys		Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys
	3		His		His	His	His	His		His		His	His	His	His	His	His
	4		Leu				Leu	Leu		Leu		Leu	Leu	Leu	Leu	Leu	
							Val						Val	Val	Val		
							Ile						Ile	Ile	Ile		
CPM Dairy	2	Ile	Ile		Ile	Leu	Ile	Ile	Ile	Leu	Ile	Ile	Ile	Ile	Ile	Leu	Ile
	3		Leu		Leu	Ile	Leu	Leu	Leu	Ile	Leu	Leu	Leu	Leu	Leu	Ile	Met
	4		Lys		Met		Met	Lys		Met	Met	Lys	Met	Lys	Met	Met	Leu
	5		Met				Lys	Met		Lys	Lys	Met	Lys	Met	Lys	Lys	Lys
	6		Arg				Arg			Arg		Arg		Arg	Arg	Arg	Arg
	7		Val				Val			Val		Val		Val			
							His			His				His			
Shield	1	Lys	Lys	Ile		Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys
	2	His	Ile			Ile	Ile	Ile	Ile	Ile	Ile	Ile	Ile	Ile	Ile	Ile	Ile
	3		His			His	His	His	His	His		His	His	His	His	His	His
	4						Val	Val		Val		Val	Val	Val	Val	Val	
	5							Arg						Arg			
	6													Thr			

[a] Only amino acids predicted to be supplied below 1.20 of requirements are listed.
[b] The sequence of limiting amino acids as predicted by each of the models.

Table 8
Amino acid supplementation package sizes, and amino acid profiles (g/kg of the package), as predicted by 'Amino Cow', 'CPM Dairy' and 'Shield' to bring all amino acids to 1.30, 1.20 or 1.10 of estimated requirements.

	Package g/d	Met	Lys	His	Ile	Leu	Val	Arg	Thr
To 1.30									
Amino Cow	86.4	205	462	10	7	259	56	0	0
CPM Dairy	143.6	61	164	0	256	347	60	112	0
Shield	85.2	0	458	95	279	0	168	0	0
To 1.20									
Amino Cow	38.2	320	607	8	0	64	0	0	0
CPM Dairy	61.1	59	117	0	368	454	0	2	0
Shield	40.9	0	566	71	316	0	47	0	0
To 1.10									
Amino Cow	13.2	508	492	0	0	0	0	0	0
CPM Dairy	13.9	0	0	0	588	412	0	0	0
Shield	9.3	0	781	0	219	0	0	0	0

feed components in the model ingredient libraries used to create the rations, as well as the assumed AA profiles of feed proteins escaping the rumen. The accuracy of these estimates is unknown.

5. Conclusions

The predicted lysine to methionine ratio in intestinally delivered protein decreased as more corn CP was included in the TMR, however it did not have a major impact on the final predicted AA profile of MP. Regardless of the effect that corn CP had on AA entering the intestine, the changed AA ratios in MP did not have an impact on milk component levels, and only Shield predicted an effect thereof on milk yield.

The metabolic models suggested three dramatically different AA packages with 'Amino Cow' suggesting inclusion of methionine and lysine, 'CPM Dairy' suggesting isoleucine and leucine and 'Shield' suggesting inclusion of lysine and isoleucine as first limiting AA in order to meet predicted requirements. There appears to be a high degree of consistency within model in predicting the limiting AA sequence among dairies, even though there is a substantial variation in predicted AA and MP levels delivered by the rations among diaries.

While there is sufficient consistency in the AA profiles of MP among rations to support production of a ruminally protected AA complex, which could balance model predicted AA profile, thereby leading to increased animal productivity and efficiency of utilization of nutrients, there is no absolute way to decide which model is most accurate. However, since Shield evaluations suggested a higher correlation between AA (both Lys and Met) and milk production, and predicted AA ratios with milk responses related to these ratios, using the ruminally protected AA package predicted by Shield is supported.

Acknowledgements

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