Application of Cornell Net Carbohydrate and Protein System to Lactating Cows in Taiwan

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ABSTRACT : The aim of this study was to apply the Cornell net carbohydrate and protein system (CNCPS) in subtropical Taiwan. This was done by means of 3 trials, viz, *in situ*, lactation and metabolic trials, the latter using the urinary purine derivatives (UPD) to estimate the ruminal microbial yield. Dietary treatments were formulated according to different nutrient requirement systems including, (1) a control NRC78 group on NRC (1978), (2) a NRC88 group on NRC (1988), and (3) a CNCPS group on Cornell Net carbohydrate and protein system model. Results from the lactation trial showed that DM intake (DMI) was higher ($p<0.05$) in the NRC78 than the other treatment groups. The treatments did not significantly influence milk yield, but milk yield after covariance adjustment for DMI was higher in the CNCPS group ($p<0.05$). The FCM, milk fat content and yield were greater in both the NRC78 and the NRC88 group over the CNCPS group ($p<0.05$). The treatments did not significantly influence the DMI adjusted FCM. The solid-non-fat and milk protein contents were higher in the CNCPS group ($p<0.05$) with or without DMI covariance adjustment. Lactating efficiency was higher in the CNCPS group ($p<0.05$) compared to the other groups. The significantly lowest milk urea-N (MUN) with better protein utilization efficiency in the CNCPS group ($p<0.05$) suggested that less N would be excreted into the environment. Cows in the CNCPS group excreted significantly more and the NRC88 group significantly less urinary purine derivatives (UPD) implying that more ruminal microbial protein was synthesized in the CNCPS over the NRC88 group. The CNCPS could become the most useful tool in predicting the trends in milk yield, microbial yield and MUN. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 6 : 857-864)***

Key Words : Cornell Net Carbohydrate and Protein System, Lactating Cow, Urinary Purine Derivatives, Production Performance, Milk Yield, Milk Composition

INTRODUCTION

To survive under free international trading environment, modern dairy farmers must utilize their limited resources to maximize production efficiency and capability to compete with the foreign producers while their environment must also be preserved. Nutritional management must depend on a sophisticated model or system to achieve the goal. Dairy diets based on the NRC (1978) crude protein system could not supply the required metabolizable protein that is beyond the capacity of ruminal microbial protein synthesis in early lactation (NRC, 1989). Under this circumstance, increased dietary crude protein intake may only increase ammonia concentration in the rumen and therefore plasma urea concentration, leading to adverse effects on production and reproduction (Jordan and Swanson, 1979). The absorbed protein system (NRC, 1988) which utilizes both rumen degradable and undegradable proteins has proven to be superior to the NRC crude protein system in Taiwan with respect to milk yield and production efficiency in early lactating cows (Chiou et al., 1995a) and dairy goats (Lee et al., 2001). Fishmeal is an excellent source of rumen undegradable protein which can partially substitute for soyabean meal in high yielding cows during early lactation (Hussein and Jordan, 1991; Broderick, 1992). Fishmeal however, occasionally did not produce beneficial results (Mantysaarim et al., 1989; Chiou et al., 1997). It appears that several factors in addition to absorbable protein, i.e., the energy content in the diet, the amino acid profile of the rumen undegradable protein, mean milk yield and lactation period, and the digestion and absorption, should be considered simultaneously in ration formulation. A dynamic computer model is required to account for the factors in nutrient requirement. Using a dynamic computer model assumes that the feed ingredients can affect the absorbable nutrients, hence potential performance. The Cornell Net Carbohydrate and Protein System (CNCPS) is a computer kinetic sub-model to synchronise the rate of supply of fermentable energy with the availability of dietary protein degradation products, leading to maximal microbial cell and protein synthesis. This system also predicts the nutrient requirements for lactating cows (Sniffen et al., 1992; O'Connor et al., 1993; Fox et al., 1995). This trial is therefore a comparision of CNCPS with early feeding systems.

MATERIAL AND METHODS

Experimental diet formulation

With an additional 10% safety factor to allow for variations in ingredient composition, experimental diets were calculated based on the average live-weight and milk

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Table 1. Ingredients and nutrient composition of the experimental total mixed rations for lactating cows (g/kg DM)

Ingredients	Control	NRC88	CNCPS
Corn silage	400.0	400.0	400.0
Alfalfa hay	100.0	100.0	100.0
Barley	243.7	30.0	292.5
Yellow corn	30.0	256.0	30.0
Soyabean meal	179.0	144.0	87.0
Protected fat	15.0	15.0	15.0
Fishmeal	0	27.5	53.0
Sodium bicarbonate	15.0	15.0	15.0
Dicalcium phosphate	6.1	3.8	0.0
Limestone	5.2	2.7	1.5
Salt	5.0	5.0	5.0
Premix[1]	1.0	1.0	1.0
Total	1,000.0	1,000.0	1,000.0
Calculated nutrient value			
Crude protein	165.0	165.0	165.0
NEL (MJ/kg)	7.11	7.11	7.11
Undegradable N (g/kg CP)	300.0	360.0	360.0
NDF	301.0	276.4	311.2
ADF	187.2	189.3	182.4
Soluble protein (g/kg CP)	264.1	274.8	240.3
NPN (g/kg soluble CP)	524.0	501.1	598.4
NDFIP (g/kg CP)	108.4	147.3	167.5
ADFIP (g/kg CP)	50.4	47.3	46.1
Starch	230.2	256.7	254.2
Analysed nutrient value			
CP (g/kg)	160.1	160.2	160.2
NDF	365.5	368.1	388.9
ADF	176.1	177.4	170.0
Soluble protein (g/kg CP)	210.6	247.1	284.4
NPN (g/kg soluble CP)	512.0	438.1	712.0
NDFIP (g/kg CP)	184.5	162.5	212.2
ADFIP (g/kg CP)	65.0	60.1	60.7
Starch	239.3	211.1	274.4

[1] Each kilogram premix contains: Vitamin A, 10,000,000 IU; Vitamin E, 70,000 IU; Vitamin D_3 1,600,000 IU; Fe, 50 g; Zn, 40g; Mn, 40 g; Co, 0.1 g; Cu, 10 g; Se, 0.1 g.

CP represents crude protein, NDF, ADF represent neutral and acid detergent fiber, respectively; NDFIP and ADFIP represent neutral and acid detergent fiber insoluble protein, respectively.

yield of the cows. The experimental diets presented in Table 1 were formulated to be iso-energetic (NEL 7.11 MJ/kg) and iso-nitrogenous (16.5% CP) total mixed ration (TMR) with roughage to concentrate ratio of 50:50. The roughage consisted of four parts of corn silage with one part of alfalfa hay on a DM basis. Concentrates were made up from barley, corn, soybean meal, protected fat and fishmeal. Dietary treatments included diets calculated according to different nutrient requirement systems that included, (1) a control NRC78 group given a TMR based on NRC (1978), (2) a NRC88 group based on NRC (1988), and (3) a CNCPS group based on Cornell Net carbohydrate and protein system model (Sniffen et al., 1992). The control diet with soybean meal, a moderately degradable protein source, as the major protein source contained less rumen undegradable protein (30% of CP) than the NRC88 and CNCPS diets (36% of CP) in which there was partial substitution of soybean meal with fishmeal. The CNCPS group diet was calculated using the CNCPS model that has a computer kinetic sub-model that considers the rates of degradation of both carbohydrate and protein in order to maximize microbial protein synthesis in the rumen. The sub-model uses digestive kinetic characteristics of the protein and carbohydrate fractions in the feedstuff to formulate the diet.

Animals and management

Feeding trial : The experiment was a complete randomized design with three dietary treatments. Twenty-four cows were selected from a Holstein herd producing on average 30±2.3 kg milk within the first three-months of lactation and were randomly allocated into one of the three dietary treatments according to live-weight, milk yield and number of lactation. After one week of adaptation, these cows were placed into an eight-week lactation trial. Cows were individually hand fed *ad libitum* in three equal meals per day at 09:00, 17:00 and 23:00 h (allowing for 2 kg leftovers) and were milked twice daily at 05:00 and 16:00 h.

Since subtropical weather is not favorable for dairy cows and heat stress is a severe problem, the dairy barn inside temperature was monitored continuously during the experimental period using an automatic temperature and humidity recorder. The dry matter intake and milk yields of the experimental cows were recorded daily, but diets and milk were sampled once weekly. Equal amounts of morning and evening milk were mixed, potassium dichromate (0.5 mg/L) was added as preservative and the milk was stored at 4°C for analysis. The cow body condition scores (BCS) and the live-weights were measured at the beginning and end of the trial according to the 5-point scale from the beef improvement federation (1989). Blood samples were collected at the beginning and end of the trial, 3 to 4 h postprandial from the vein, and serum was stored at -4°C for further analysis.

In situ trial : Three ruminal fistulated Holstein dry dairy cows averaging 600 kg live-weight were placed in individual 50 m^2 pens with cement floors with a holding stanchion inside. After feeding 10 kg (as fed) TMR, presented in Table 2, in two equal meals daily for a ten day adaptation period, cows were fed the TMR in evenly divided amounts six times daily (four hour periods) 01:00,05:00, 09:00, 13:00, 17:00 and 21:00 during the *in situ* nylon bag incubation period to minimize ruminal fluctuation. The ruminal incubation procedure was conducted according to the modified method of Chiou et al. (1995b), in which 8 g of the experimental TMR sample was placed into a 20×10 cm polyester bag (Ankom Co. Ltd,

Table 2. Ingredients and nutrient composition of experimental total mixed ration for ruminal fistulated dry Holstein cows (DM basis)

Ingredients	g/kg
Bermuda hay	500.0
Yellow corn	249.0
Soyabean meal	122.5
Wheat bran	100.0
Limestone	10.0
Dicalcium phosphate	15.0
Salt	2.5
Premix[1]	1.0
Total	1,000.0
Calculated nutrient (g/kg dry basis)	
NEL (MJ/kg)	5.44
Crude protein	15.0
Neutral detergent fiber	410.0
Acid detergent fiber	280.0
Calcium	7.0
Phosphorous	5.0

[1] Each kilogram premix contains: Vitamin A, 10,000,000 IU; Vitamin E, 70,000 IU; Vitamin D_3 1,600,000 IU; Fe, 50 g; Zn, 40g; Mn, 40 g; Co, 0.1 g; Cu, 10 g; Se, 0.1 g.

Spencerport, NY) of 53×10 μm pore size. After placing into warm water for 30 min, all four replicate samples from each of the ten ruminal incubation periods, except samples from the 0 h incubation, were placed into the ventral sac of the rumen in reverse order, i.e., 72, 48, 36, 30, 24, 18, 12, 6, and 3 h. After incubation, samples were withdrawn from the rumen and put in ice-water to stop the microbial fermentation and were then mechanically washed three times by laundry machine in 14 L of water for 1.5 min,, dried in the 60°C forced-air oven for 48 h, and stored for the further analyses of dry matter, ash, crude protein and starch. The degradation model was conducted according to Ørskov and McDonald (1979) and calculated using iterative least square procedures according to SAS (1995)

Metabolic trial : At the end of the lactation trial, three cows from each treatment group were selected for a three-day urinary collection in the metabolic trial. Urine collection bags were installed on the cows and urine was collected in 40 L plastic containers. Urine was acidified immediately after collection using 2.5 L of 1 M H_2SO_4 to ensure low urinary pH (below 3). A 200 mL urinary sample was collected daily and stored at -20°C for analysis of urinary purine derivatives.

Chemical analysis

Feed samples were dried at 60°C in a forced-air oven for 48 h, ground through a 2 mm screen and stored at -18°C for further analysis. Proximate analysis of feed samples was conducted according to AOAC (1980). Neutral detergent fiber (NDF) and acid detergent fiber (ADF), lignin, neutral detergent insoluble nitrogen (NDFIP) and acid detergent insoluble nitrogen (ADFIP) were analyzed according to Van Soest et al. (1991). The NPN in soluble crude protein was determined by subtraction of the tungstic acid precipitated protein from crude protein. Soluble protein in crude protein was determined via borate phosphate buffer according to the method of Licitra et al. (1996) and Krishnamoorthy et al. (1982). Starch was determined according to the method of Chiang and Johnson (1977).

The milk constituents including fat, protein, lactose and total solids were analyzed using a milk scanner (Milko Scan 255 A/B type, Foss Electric Co.) according to AOAC (1980). The milk urea nitrogen was analyzed using a test kit (Sigma Diagnostics #535, Sigma Co., USA) and a spectrophotometer at 540 nm according to the method of Crocker (1967). The serum urea nitrogen was analyzed with an automatic blood chemical analyzer (Hitachi 7050 Automatic analyzer).

After the urinary sample was centrifuged for 5 min at 3,000 g, the precipitate was removed; uric acid and creatinine were determined using a urinary analyzer (CX5CE, USA). Allantoin was determined using a spectrophotometer (UV-2000, Hitachi, Japan) at 530 nm according to the method of Fujihara et al. (1987).

Statistical analysis

The degradation model for the *in situ* data was followed according to Orskov and McDonald (1979) and was calculated using iterative least square procedures. The milk yield was adjusted for the dry matter intake using covariance analysis according to SAS (1995).

Analysis of variance was calculated with the General Linear Model (GLM) of the Statistical Analysis System Institute Inc. (1995). Duncan's new multiple range test was used to compare the treatment means (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

The degradability of the experimental diets

Degradation characteristics and effective degradability of the dry matter (DM), organic matter (OM), crude protein (CP) and starch of the total mixed experimental rations are presented in Table 3. The degradation characteristics represented a non-linear degradation curve ($P = a+b(1-e^{-ct})$); "P" is the actual degradation after time t, whereas "a" is the fraction (percentage) of soluble material present at initiation of incubation, "b" is the portion potentially degradable in the rumen, and "c" is the degradation rate constant (%/h) of "b" or the slope of the degradation curve. The effective degradability of the nutrient ($ED = a+bc/(c+k)$) was calculated at the rumen solid outflow rates of 5 or 8%/h (k).

The rates of disappearance of the potentially degradable portion of the DM, OM and starch were faster in the control

Table 3. Degradation characteristics and effective degradability of dry matter, organic matter, crude protein and starch of the experimental TMR

Total mixed ration	Degradation characteristics[1]			Effective degradability outflow rates[2] (% h^{-1})	
	a	b	c	5	8
Dry matter					
Control	23.4	58.3	12.3	64.9	58.8
NRC88	20.1	61.1	10.1	60.9	54.1
CNCPS	22.3	56.0	17.6	65.9	60.8
Organic matter					
Control	18.9	51.5	11.8	55.1	49.7
NRC88	15.3	54.6	9.7	51.9	45. 8
CNCPS	18.4	49.6	16.8	52.3	46.9
Crude protein					
Control	32.6	53.9	11.09	69.6	63.8
NRC88	33.0	57.2	6.5	65.3	58.6
CNCPS	34.2	61.8	6.0	67.9	60.6
Starch					
Control	46.1	52.4	33.2	91.6	88.3
NRC88	38.0	60.0	27.8	88.8	84.6
CNCPS	31.9	67.0	66.7	94.2	91.7

[1] a = The percentage of nutrient soluble at initiation of incubation; b = the percentage of nutrient potentially degradable in the rumen; and c = the constant rate (percentage per h) of disappearance of b.

[2] Effective degradability of nutrient calculated for solid outflow rates 5 or 8 (% h^{-1}).

and the CNCPS groups compared to the NRC88 group; this reflects faster starch degradation in barley in both the control and CNCPS groups than cornstarch in the NRC88 group.. Nocek and Tamminga (1991) indicated that between 80 to 90% of barley starch and wheat starch was digested in the rumen whereas only 55 to 70% of sorghum and cornstarch were digested in the rumen. This is due to the more rapid rate of ruminal fermentation of barley grain starch relative to that of corn. This also reflected the higher effective degradation rate of DM, OM and starch in the control and the CNCPS group, both at 5 and 8%/h ruminal solid outflow rates. The soluble ("a" fraction) and potential degradable CP ("b" fraction) was lower in the control diet than in the other dietary groups reflecting high ADFIP ("c" fraction) in the control diet (Table 3). The effective degradation rate of CP showed a reverse trend (higher) in the control diet than the other diets reflecting the substitution of the rapidly degradable soybean meal by the low degradable fishmeal (Genesh and Grieve, 1990; Chiou et al., 1997). The high soybean meal content of the control diet resulted in a high protein degradability, calculated at both 5 and 8 %/h ruminal solid outflow rate. These degradation characteristics also reflected the designed experimental dietary treatment with lower degradable protein in the control than the other dietary groups and higher degradable starch, DM and OM in the CNCPS group as compared to the NRC88 group.

Effect on dry matter intake

The lactation trial was conducted during the spring season from March to April in the subtropical area of Pingtung County, Southern Taiwan where the weather was becoming warmer and both the feed intake and milk yield were starting to decline. The weekly means of the inside barn temperature and humidity were maximum 30 to 31.5°C and 80 to 87.4% and minimum 20 to 23.4°C and 44.4 to 45.4%, respectively.

Table 4 presents the dietary treatment effects on the DMI, milk yield, milk composition and production efficiency of lactating cows. DMI showed a significant difference between the treatments with more DMI ($p<0.05$) in the control than the treatment groups where the DMI in the CNCPS group was lowest ($p<0.05$). DMI was not affected by the presence of fishmeal if it replaced no more than 3.5% of the soybean meal in feeding early lactating Holstein cows. Carrol (1994) found that this did not significantly affect DMI. Chiou et al. (1997) substituted soybean meal with 4.5% fishmeal and found no significant effect on DMI. Spain and Poland (1995) however, demonstrated reduced DMI when the diet contained more than 5.2% fishmeal. The intake depression from fishmeal inclusion in the diet might be attributed to the high unsaturated fatty acid content in the fish oil which is more susceptible to rancidity, fish taint and decreased palatability (Windschitl, 1991). The level of fishmeal inclusion in this trial increased from 0 in the control to 2.75% in the NRC88 group, and 5.3% in the CNCPS group. The dairy cows in this trial had never experienced fishmeal in their diet, and the presence of this novel ingredient may have been the reason for a decrease in DMI.

Effects on milk yield

Treatments did not significantly influence milk yield ($p>0.05$) (Table 4). Different DMI will produce different milk yield even on the same diet. The DMI in this trial was different ($p<0.05$). These diets should be reformulated when predicted differed from the actual DMI in practical feeding situations. The necessary adjustments could not be made during this feeding trial. After DMI adjustment through covariance analysis, milk yield was influenced by treatment ($p<0.05$) (Table 4). This indicated that a diet formulation by the CNCPS would give a higher milk yield at the same DM intake.

Treatment significantly affected the 4% fat corrected milk (FCM) yield ($p<0.05$). The CNCPS group produced a lower FCM than the control and the NRC88 groups ($p< 0.05$). This may be attributed to the different DMI because the treatment did not influence the DMI adjusted FCM ($p>0.05$). Feeding a fishmeal diet to lactating cows decreased the milk fat content and FCM (Spain et al., 1990;

Table 4. Effects of dietary treatment on dry matter intake, milk yield, milk composition, production efficiency of lactating cows

Item	Control	NRC88	CNCPS	SEM
Production performance (kg/day)				
Dry matter intake	18.35[a]	16.80[b]	15.39[c]	0.90
Milk yield	28.98	29.62	29.73	0.80
4% FCM	27.48[a]	28.26[a]	25.67[b]	1.02
Milk composition (%)				
Solids-non-fat	8.46[ab]	8.37[b]	8.58[a]	0.11
Milk fat	3.54[a]	3.70[a]	3.14[b]	0.17
Milk protein	2.82[ab]	2.74[b]	2.88[a]	0.10
Milk component yield (kg/day)				
Solids-non-fat	2.49	2.47	2.53	0.09
Milk fat	1.05[a]	1.10[a]	0.92[b]	0.05
Milk protein	0.83	0.81	0.85	0.04
After adjustment for DM intake (kg/day)				
Milk yield	28.46[b]	28.69[b]	30.82[a]	0.39
4% FCM	27.08	26.96	26.69	0.98
Solids-non-fat	2.42[b]	2.37[b]	2.67[a]	0.05
Milk fat	1.03[a]	1.04[a]	0.96[b]	0.06
Milk protein	0.80[b]	0.79[b]	0.89[a]	0.03
Efficiency of nutrient utilization (kg/kg)				
DM intake/milk yield	0.63[a]	0.59[b]	0.53[c]	0.03
DM intake/FCM yield	0.65	0.63	0.63	0.04
NE intake/FCM yield (MJ/kg)	5.344	4.435	4.435	0.251
CP intake/FCM yield	0.115[a]	0.108[b]	0.112[ab]	0.002
CP intake/milk CP yield	3.95[a]	3.69[b]	3.31[c]	0.08

[a, b, c] Means in the same row with different superscripts are significantly different ($p<0.05$).

Windschetl, 1991) due to the depressing effect of the poly-unsaturated fatty acids from fishmeal on the acetate and acetate to propionate ratio in rumen fermentation (Windschetl, 1991). This low milk fat content in the CNCPS group on a high fishmeal inclusion diet may explain the increase in milk yield but not FCM yield obtained after covariance adjustment for DMI.

Effect on milk composition

The dietary treatments significantly affected the milk composition, including solids-non-fat (SNF), fat and protein ($p<0.05$). The treatments significantly decreased the milk fat content in the CNCPS group ($p<0.05$). The treatments however increased the SNF and milk protein content significantly more in the CNCPS group than the NRC88 group ($p<0.05$). This high milk protein content may be attributed to the high fishmeal and higher rate of degradation of barley compared to corn. Fishmeal contains higher amounts of lysine and methionine that increase protein synthesis in the milk gland (Santos et al., 1998) and synchronization of the supply of fermentable carbohydrate and protein may also have improved microbial protein synthesis in the rumen (Nocek and Russell, 1988) with the result that more milk protein was produced. In our trial, the CNCPS diet that contained high levels of fishmeal with barley as the major grain source, promoted the highest microbial protein synthesis as shown by the high urinary purine derivatives excretion (Table 5), and also produced the highest milk protein content.

Effect on production efficiency

The dietary treatments significantly influenced the amount of DM required per unit milk yield ($p<0.05$) as predicted since diet formulation based on NRC78 did not consider requirements of ruminal microbes (degradable protein) and animal (undegradable protein) separately (NRC, 1988). Diet formulation on the CNCPS system promotes ruminal microbial synthesis with provision of both energy and protein at the same time as compared to the NRC88 diet and therefore is more efficient in both protein and energy utilization (Nocek and Russell, 1988). The CNCPS diet therefore was significantly ($p<0.05$) more efficient in conversion of feed to milk, followed by the NRC88 group, and the control group had the least feed conversion efficiency for milk production ($p<0.05$). The CNCPS group produced more milk per unit of DMI (Table 3). These differences did not exist in the FCM yield because the CNCPS diet produced less milk fat compared to the other treatment groups. This situation was also true for the amount of net energy (NEL) required to produce a unit of FCM because the treatment diets were iso-energetic.

The dietary treatment significantly influenced the amount of CP required per unit FCM yield ($p<0.05$). The NRC88 group required significantly less CP to produce a unit of FCM ($p<0.05$). This may be attributed to the control group requiring significantly more feed and producing a

Table 5. Effects of dietary treatment on body condition, serum and milk urea nitrogen, urinary uric acid, allantoin and creatinine of lactating cows

Item	Control	NRC88	CNCPS	SEM
Initial BCS[1]	2.50	2.38	2.20	0.18
Final BCS	2.50	2.47	2.29	0.12
Final body weight (kg)	543	519	487	32.9
Urea nitrogen (mg/dL)				
Serum urea nitrogen	16.79	16.54	13.21	2.12
Milk urea nitrogen	14.27[a]	13.58[ab]	12.82[b]	0.81
Urinary				
Uric acid (g/d)	0.55	0.44	0.55	0.12
Allantoin (g/d)	19.04[ab]	11.65[b]	26.60[a]	5.33
Creatinine (g/d)	0.63	0.71	0.84	0.16

[1] Body weight change 56 kg per unit of body condition score (BCS) change according to Otto et al. (1991) whereas 4.92 Mcal NEL per kilogram of live-weight change according to NRC (1988).

[a, b, c] Means in the same row with different superscripts are significantly different ($p<0.05$).

similar amount of milk compared to the NRC88 groups under the iso-nitrogenous diets. Cows in the CNCPS group required significantly less protein to produce a unit of milk protein followed by the NRC88 group. The cows in the control group required the greatest amount of crude protein to produce a unit of milk ($p<0.05$). The CNCPS group presented the most efficient protein conversion with the least amount of required DMI on the iso-nitrogenous diet and produced significantly more milk protein with a similar amount of milk protein yield compared to the other treatment groups. The control group had the lowest protein conversion efficiency because the diet contained the least amount of undegradable protein (Table 1), below the cow requirement for milk production. The higher ratio of degradable to undegradable protein in the control diet resulted in significantly higher milk urea nitrogen compared to the other treatment groups (Table 5).

Effect on serum and milk urea nitrogen

Table 5 presents the dietary treatment effects on body condition score, serum and milk urea nitrogen concentration, and the metabolites excreted in urine. All cattle body condition scores were improved at the end of the trial. This indicates there was positive energy retention during the lactation trial. The treatments did not significantly influence serum urea nitrogen. However, there was a trend towards lower serum urea nitrogen values in the CNCPS group ($p<0.10$) compared to the other treatment groups. Milk urea nitrogen concentration was significantly lower in the CNCPS group as compared to the control group ($p<0.05$) and reflected a significantly lower nitrogen excretion into the environment by the CNCPS group. Serum and milk urea nitrogen level reflects the dietary protein and energy balance (Roseler et al., 1993). When the supplement exceeds the recommended amount of degradable or undegradable protein (NRC, 1988), there is an increased urea nitrogen concentration both in the blood and milk (Baker et al., 1995). Data from this trial showed a lower urea nitrogen concentration in the milk and urea in the CNCPS group which was indicative of a better protein utilization efficiency (Table 4), more microbial protein synthesized in the rumen (Table 5) and less nitrogen excreted into the environment.

Effect on urinary purine derivatives

The treatments did not significantly affect the amount of uric acid and creatinine excretion ($p>0.05$), but significantly influenced allantoin excretion ($p<0.05$) (Table 5). Other research has shown a positive relationship between the urinary purine derivatives (uric acid and allantoin) and microbial protein synthesis in the rumen (Fujihara et al., 1987; Chen et al., 1990; Verbic et al., 1990; Vagnoni et al., 1997). Increased microbial protein synthesis in the rumen will increase the absorbed microbial protein and increase protein utilization. Cows in the CNCPS group excreted significantly more allantoin in their urine than the NRC88 group implying greater ruminal microbial growth in the CNCPS group. The control group showed a trend towards more allantoin excretion compared to the NRC88 group ($p<0.10$). Generally, the faster ruminal fermentation rate of barley starch relative to that of corn provides more rapidly available energy to promote ruminal microbial protein synthesis (Lee et al., 1986; Spicer et al., 1986; McCarthy et al., 1989). More degradable protein content in the control diet with rapidly available energy led to more microbial protein synthesis in the control group. In the *in situ* trial, the rate of disappearance of the potential degradable DM portion, OM and starch was also faster in the control and CNCPS groups compared to the NRC88 group reflecting faster barley starch degradation than corn. Barley was substituted for corn in both the control and CNCPS groups (Table 3).

Using CNCPS as a diagnostic tool in nutrition management

Table 6 presents the predicted value from the CNCPS computer model and the actual performance data for lactating cows. The predicted to actual DMI is quite close in the control group (18.0 vs. 18.4 kg/d), different in the NRC88 group (18.3 vs. 16.8 kg/d) and was greatly different in the CNCPS group (18.0 vs. 15.4 kg/d). Although the CNCPS model takes account of factors including different types of feed, animals and environmental conditions, it still over estimates the DMI (Eastridge et al., 1998; Kohn et al., 1998; Kolver et al., 1998).

Although the predicted milk yields (29.9, 31.4 and 33.5 kg/d) showed a similar increasing trend to the actual milk

Table 6. Predicted and actual performance data of lactating cows

Item	Control	NRC88	CNCPS
Predicted ME available (Mcal/d)	49 (2.7 Mcal/kg)	51 (2.8 Mcal/kg)	50 (2.8 Mcal/kg)
Dry matter intake (kg/d)			
Actual	18.4	16.8	15.4
Predicted	18.0	18.3	18.0
Milk yield (kg/d)			
Actual	29.0	29.6	29.7
Actual (adjust DMI)	28.5[b]	28.7[b]	30.8[a]
Predicted from ME[1]	29.9	31.4	33.5
Predicted from MP[2]	32.9	35.8	36.9
Predicted from AA[2]	38.5	44.1	47.1
Predicted MP available (g/d)	2,103	2,160	2,261
From bacteria (g/d)	1,326 (63.0%)	1,243 (57.6%)	1,287 (57.0%)
From undeg. feed (g/g)	777 (37.0%)	917 (42.4%)	973 (43.0%)
Allantoin (g/d)	19.04[ab]	11.65[b]	26.60[a]
MUN[3] (mg/dL)			
Predicted	12	13	11
Actual	14.27[a]	13.58[ab]	12.82[b]

[a, b, c] Means in the same row with different superscripts are significantly different ($p<0.05$).
[1] ME represent metabolizable energy, [2] MP: metabolizable protein; AA: amino acids. [3] MUN: milk urea nitrogen.

yield after DMI adjustment (28.5, 28.7 and 30.8 kg/d), differences between the predicted and actual yields were still great. The predicted bacterial protein trend did not agree with the estimated allantoin excretion trend and requires further investigation. The milk urea nitrogen trend however was similar for the predicted and actual measurements.

With better lactation efficiency and microbial production, the CNCPS system can be applied to ration formulation; however the differences were still great. The CNCPS system will require further modification before it can be practically applied in Taiwan.

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