Evaluation of Tropical Grasses for Milk Production by Dual-Purpose Cows in Tropical Mexico

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ABSTRACT

Two experiments using the Cornell Net Carbohydrate and Protein System were conducted to characterize the carbohydrate and protein fractions and corresponding rates of digestion of 15 tropical pasture grasses and to evaluate their ability to support milk production by dual-purpose cows. In the first experiment, ranges in carbohydrate and protein fractions of 15 grasses at 35 to 42 d of regrowth were: neutral detergent fiber (NDF) 63.5 to 74.9% of DM; permanganate lignin 4.7 to 7.8% of NDF; CP 5.5 to 11.9% of DM; and soluble protein 15.1 to 44.1% of crude protein (CP). The ranges of rates of digestion expressed as percent per hour were neutral detergent solubles (7.5 to 27.4); NDF (3.8 to 8.4); and neutral detergent insoluble protein (2.9 to 9.5). Predictions of the amount of milk that could be produced based on the amount of metabolizable energy supplied by the diet decreased 35% when NDF increased from 60 to 80%, and increased 88% when the rate of digestion of NDF increased from 3 to 6%/h. The milk production that could be sustained based on metabolizable protein in the diet doubled as CP increased from 4 to 12%. In the second experiment, nitrogen fertilization reduced NDF 7.3% and increased CP 84% without changing protein solubility, resulting in increased rumen nitrogen and metabolizable protein balances. With all forages, the Cornell Net Carbohydrate and Protein System predicted that availability of metabolizable protein would limit milk production. Predicted microbial growth was limited by ruminally available protein rather than by available carbohydrate.

(**Key words:** tropical grasses, milk production, nutritive value)

Abbreviation key: CNCPS = Cornell Net Carbohydrate and Protein System, **EB** = energy balance, **ME** = metabolizable energy, **MP** = metabolizable protein, **NDIP** = neutral detergent insoluble protein, **NDS** = neutral detergent solubles, **NE$_m$** = net energy for maintenance, **NSC** = nonstructural carbohydrates, **PKMK** = month of peak milk production, **SC** = structural carbohydrates, **SBW** = shrunk BW, **UIP** = undegradable intake protein.

INTRODUCTION

Much of the milk in the tropics is produced by dual-purpose cows (23). These dual-purpose cows are used to harvest nutrients from predominantly grass pastures for the production of milk and meat. Nutritional systems are needed to predict milk production by cows on pastures of varying nutritive value under the prevailing environmental conditions, and to design supplements that will complement available forages to meet production objectives.

Our first objective was to use information on carbohydrate and protein fractions and the corresponding digestion rates of 15 tropical grasses from a semihumid region of Mexico to evaluate the ability of these forages to support milk production in dual-purpose cows using the Cornell Net Carbohydrate and Protein System (CNCPS) model. A second objective was to evaluate the effect of N fertilization of tropical grasses on CNCPS-predicted metabolizable energy (**ME**) and metabolizable protein (**MP**).

MATERIALS AND METHODS

Two experiments were conducted to characterize the carbohydrate and protein fractions and the corresponding digestion rates of tropical grasses, and to evaluate the ability of these forages to support milk production by dual-purpose cows. In the first experiment, we measured the carbohydrate and protein fractions and their digestion rates in 15 tropical grasses to predict and evaluate the effects of pool size and digestion rate on milk production using the CNCPS modified for use in the tropics. In the second experiment, we measured the carbohydrate and protein fractions in four of these tropical grasses grown with or without nitrogen fertilization, and predicted the effect of nitrogen fertilization on milk production using with the CNCPS model. Throughout this paper, version 3.0 of the CNCPS as

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TABLE 1. Data on lactating dual purpose cows used for evaluating tropical grasses with the Cornell Net Carbohydrate and Protein System model.

Item	Mean[1]	SD	Minumum	Maximum
Lactation, no.	5.3	2.38	3	12
Milk, kg/d	10.4	3.28	5.3	20.4
DIM	174	113.7	30	450
BW, kg	511	36	440	590
ADG[2], g/d	421	711	–1633	1433

[1] Includes 50 lactations of crossbred (¾ × ¼ Zebu) cows.

[2] Average daily gain.

TABLE 2. Animal and environment descriptions used in the Cornell Net Carbohydrate and Protein System model to evaluate forages.

Description	Input	Units
Animal Type	2	Lactating dairy cows
Age	66	mo
Sex	4	cow
Body Weight	511	kg
Breed Type	2	Beef * dairy (dual purpose)
Mature Weight	550	kg
Condition Score	3	(1 = Thin to 5 = fleshy)
Breeding System	2	way cross
Dam's Breed	17	Brahman
Bull's Breed	15	Holstein
Days Pregnant	55	d
Days since Calving	174	d
Lactation #	5	
Rolling Herd Average	2866	kg
Milk Production	10	kg/d
Milk Fat	3.6	%
Milk Protein	3.2	kg %
Relative Milk Production	5	(1 to 9 scale to estimate milk production)
Expected Calf Birth Weight	38	kg
Management Description		
Additive	1	None
Grazing Unit Size	27	hectares
Daily Pasture Allowance	1	$DMI_{actual}/DMI_{potential}$
Initial Pasture Mass	3000	kg/hectare
Feeding Frequency	24	(number of times per day)
Feeding Method	1	(Forage and grain offered separately)
Environmental Description		
Wind Speed	16	kph
Previous Temperature	27	°C
Current Temperature	28	°C
Storm Exposure	1 =	Yes
Night Cooling	1 =	No cooling
Hair Depth	0.6	cm
Hide	1 =	Thin
Hair Coat	1 =	No mud
Cattle Panting	1 =	None

[1] For details on CNCPS input options see references (5) and (7).

described by Russell et al. (18), Sniffen et al. (20), and Fox et al. (7) with modifications for use in the tropics as described by Fox et al. (6) was used. Forages were evaluated by the procedures described by Fox et al. (5). Inputs used to describe the dual-purpose cows for the forage evaluation were based on data from 50 lactations of crossbred (¾ Holstein × ¼ Zebu) cows (Table 1). Weather data collected in August at the experiment station where the forages were grown provided the environmental inputs for the CNCPS model (Table 2).

Experimental Site and Weather

The study was conducted at the National Institute of Agroforestry and Animal Science Research experiment station located on the southeastern coast of Mexico near the city of Veracruz. The climate of the area is characterized as tropical subhumid Aw following Köppen's classification of tropical climates, indicating that no month has an average temperature below 18°C and that there is a dry season (9). The local meteorological station (Centro de Prevision del Golfo) reported a mean rainfall of 1728 mm/y and a rainy season from June to November. The mean temperature and relative humidity in August were 25°C and 81%, respectively.

Experiment 1. Carbohydrate and Protein Fractions in 15 Tropical Forages

The 15 different species of tropical grasses were grown in pure stands. Initially, all plots were cut to a height of 5 cm. At 35 and 42 d of regrowth, grass samples were clipped to a height of 10 cm. Five hundred grams of each sample was dried immediately at 100°C in a forced air oven for 24 h to determine DM. An additional 500 g was frozen at –15°C prior to lyophilization and shipment to Cornell University for laboratory analyses. The samples were ground through a 1-mm screen in a Wiley mill (Model 4, Arthur H. Thomas Co. Philadelphia, PA). All carbohydrate (25) and protein (11) fractions required as inputs for the CNCPS were measured, and the digestion rates of the neutral detergent insoluble protein (**NDIP**) (8) and carbohydrate fractions (4, 15, 19) were determined. The average, minimum, and maximum values of the chemical and kinetic analyses of all 15 forages were used to predict the effects of variation in tropical forage composition on milk production using the CNCPS. The sensitivity of the model to the following input values was evaluated: NDF, permanganate lignin, CP, protein solubility, digestion rates of neutral detergent solubles (**NDS** or $A + B_1$ carbohydrate fractions), NDF (B_2 carbohydrate fraction), and NDIP (B_3 protein fraction).

In these evaluations, the amount of forage DM, the sole ingredient in the ration, was held constant at 12.7 kg to evaluate the effects of forage composition on milk production independent of concentrate and total DMI effects. The response variables of interest from the CNCPS were the amount of milk predicted from the metabolizable energy supplied (**ME** allowable milk), the amount of milk predicted from the metabolizable protein supplied (**MP** allowable milk), rumen N balance, peptide balance, MP from bacteria, and MP from undegradable intake protein (**UIP**).

Experiment 2. The Effect of N Fertilization on Carbohydrate and Protein Fractions in Tropical Grasses

Four of the 15 grass species described in Experiment 1 (*Andropogon gayanus, Brachiaria brizantha, Cynodon plectostachyus*, and *Panicum maximum*) were grown with or without N fertilization and were evaluated as described for Experiment 1. These four are commonly used grasses and have high DM yield compared to 17 other typical grasses (14). The grasses were grown in pure stands in 5-m × 5-m plots. For each grass, one plot was not fertilized and the other was fertilized with 100 kg/ha of N from urea at the beginning of the rainy season. The protocol for collection, analysis and evaluation of the forages was as described in Experiment 1, except DMI was predicted with the equation developed by Traxler et al. (21) for use with dual-purpose cows fed tropical forages. As a result, predicted milk production was influenced by the effects of changes in forage composition on both DMI and forage energy content. Fertilization effects were evaluated statistically, using MINITAB, version 10 (Minitab Inc., State College, PA).

RESULTS AND DISCUSSION

Experiment 1. Carbohydrate and Protein Fractions in 15 Tropical Forages

The results of the chemical and in vitro digestion analyses are presented in Table 3. Based on these data, ranges in values (rounded minimum, average, and maximum) were used to predict milk production responses to changes in various pool sizes and rates. These ranges were NDF (% of DM), 60, 70, and 80; permanganate lignin (% of NDF), 4, 6, and 8; NDS (A + B_1 carbohydrate fractions) rates of digestion (%/h), 6, 16 and 26; NDF (B_2 carbohydrate fraction) rates of digestion (%/h), 3, 6, and 9; CP (% of DM), 4, 8, and 12; soluble protein (% of CP), 20, 35, 50; and NDIP (B_3 protein fraction) rates of digestion (%/h), 4, 7, and 10.

TABLE 3. Carbohydrate and protein fractions and their rates of digestion in 15 tropical forages.

Item	*C. plec.*[1]	*D. dec.*	*A. gay.*	*B. bri.*[1]	*B. dec.*[1]	*B. dic.*	*B. hum.*	*E. pol.*	*M. min.*	*P. fas.*	*P. not.*	*P. max.* var. gui.	*P. max.* var. col.	*P. max.* var. ven.	*P. max.* var. tob.
DM, %	26.7	26.8	25.0	23.0	21.9	20.8	19.3	15.2	17.6	18.5	19.1	22.5	24.9	28.0	26.1
NDF, % of DM	74.7	70.0	70.2	66.1	69.6	72.4	73.6	68.3	70.2	63.5	71.0	69.3	73.7	70.8	74.9
Lignin, % of NDF	7.5	7.3	6.1	5.6	6.3	5.7	7.8	4.7	4.7	5.7	6.0	6.2	7.7	5.3	6.8
CP, % of DM	8.0	7.0	8.6	8.9	7.8	6.3	7.5	9.3	8.6	11.9	10.5	7.4	7.1	6.0	5.5
Solubility, % of CP	35.6	36.7	20.4	42.5	44.1	41.2	44.1	29.6	27.9	15.1	19.7	31.0	31.7	35.8	32.8
NPN, % of SolP	34.9	38.3	82.4	69.7	67.0	58.4	51.7	74.8	50.1	87.1	58.4	61.9	81.5	87.6	88.5
NDIP[2], % of CP	39.3	31.3	48.6	13.6	13.7	21.9	19.5	25.6	33.0	41.9	43.2	34.7	36.0	35.5	34.9
ADIP[3], % of CP	9.7	6.1	6.7	3.5	4.4	7.2	6.1	4.8	4.9	6.5	8.3	8.6	8.5	8.5	8.3
Fat, % of DM	1.3	1.8	2.0	2.3	1.8	1.5	1.7	1.8	2.5	1.2	1.4	2.5	2.2	2.0	1.8
Ash, % of DM	9.0	8.0	8.0	9.3	8.8	9.4	8.2	12.3	12.8	14.2	10.7	11.0	9.1	1.0	9.3
Unavailable NDF, % of DM[4]	13.4	12.3	10.3	8.9	10.5	9.9	13.8	7.7	7.9	8.7	10.2	13.3	13.6	9.0	12.2
Available NDF, % of DM[5]	58.1	55.5	55.7	56.0	58.0	61.1	58.4	58.2	59.4	49.8	56.2	56.4	57.5	59.7	60.8
NSC, % of DM[6]	10.1	15.4	15.4	14.6	13.1	11.8	10.5	10.7	8.7	14.2	10.9	12.4	10.5	22.3	10.4
Digestion rate, %/h NSC (CHO A + B1)	13.2	22.4	13.8	27.4	25.7	24.4	18.1	22.2	10.6	9.8	18.4	8.6	7.5	10.8	12.1
Available NDF (CHO B2)	3.8	5.2	7.3	8.4	8.1	8.1	7.7	7.5	8.0	6.3	5.5	6.8	5.5	8.1	6.0
Available NDF protein (protein B3)[7]	5.2	4.0	8.0	5.7	3.4	3.3	2.9	8.6	7.4	6.5	6.1	9.5	5.1	7.4	5.0

[1] *C. plec.* = *Cynodon plectostachyus* (n = 5); *D. dec.* = *Digitaria decumbens* (n = 3); *A. gay.* = *Andropogon gayanus* (n = 5); *B. bri.* = *Brachiaria brizantha* (n = 5); *B. dec.* = *Brachiaria decumbens* (n = 5); *B. dic.* = *Brachiaria dictyoneura* (n = 5); *B. hum.* = *Brachiaria humidicola* (n = 5); *E. pol.* = *Echinocloa polistachya* (n = 2); *M. min.* = *Melinus minutiflora* (n = 2); *P. fas.* = *Paspalum fasciculatum* (n = 2); *P. not.* = *Paspalum notatum* (n = 2); *P. max.* var. Guinea = *Panicam maximum* var. Guinea (n = 5); *P. max.* var col. = *Panicum maximum* var. coloniao (n = 3); *P. max.* var. ven. = *Panicum maximum* var. vencedor (n = 5); *P. max.* var. tob. = *Panicum maximum* var. tobiato (n = 3).

[2] NDIP = Neutral detergent insoluble protein.

[3] ADIP = Acid detergent insoluble protein.

[4] Unavailable NDF = NDF – (lignin % of NDF × 2.4).

[5] Available NDF = NDF – (CP * (NDFIP/100)) – unavailable NDF.

[6] NSC = Nonstructural carbohydrate, and is 100 – CP – fat – ash – unavailable NDF – available NDF.

[7] Available NDF protein = NDFIP – ADFIP.

TABLE 4. Expected milk production responses with changes in NDF and lignin in tropical grasses[1].

	60% NDF[2]			70% NDF			80% NDF		
	4%[3] Lignin	6% Lignin	8% Lignin	4% Lignin	6% Lignin	8% Lignin	4% Lignin	6% Lignin	8% Lignin
Metabolizable energy (ME)									
Allowable milk, kg/d	12.2	11.3	10.4	10.5	9.4	8.2	8.8	7.4	6.0
ME[4] in Grass, Mcal/kg	2.1	2.1	2	2	1.9	1.8	1.8	1.7	1.6
MP[5] Balance, g/d	145	99	53	57	2	–52	–32	–95	–158
MP Allowable milk, kg/d	8.6	7.7	6.8	6.8	5.7	4.6	5.0	3.8	2.5
Rumen N balance, g/d	–13	–6	0	–2	6	13	3	12	20
Peptide Balance, g/d	14	14	14	36	36	36	52	52	52
MP from Bacteria, g/d	708	685	661	668	640	612	626	593	560
MP from UIP[6], g/d	287	287	287	280	280	280	273	273	273

[1] The grass being evaluated was the sole dietary ingredient and was kept constant at 12.7 kg/d.

[2] Percentage of DM.

[3] Percentage of NDF.

[4] ME in grass = Cornell Net Carbohydrate and Protein System predicted ME content of the grass.

[5] MP balance = Metabolizable protein absorbed – metabolizable requirement.

[6] MP from UIP = The amount of metabolizable protein that is from undegradable intake protein.

Neutral detergent fiber and lignin. Results of the sensitivity analysis of the CNCPS to changing NDF and lignin concentrations are in Table 4. At the intermediate lignin concentration (6% of the NDF), the predicted ME allowable milk decreased 35% as NDF increased from 60 to 80%. The reduced milk production predicted as NDF increased was due to the replacement of NSC with structural carbohydrates (**SC**). The MP from bacteria decreased 13% because there was less rumen degradation of carbohydrates resulting in less microbial growth; this reduced predicted MP allowable milk by 51%. Ruminal N balance was positive because of lower microbial growth.

At the intermediate concentration of NDF (70%), increased lignin concentration reduced predicted ME allowable milk 22% as lignin increased from 4 to 8% of the NDF. The CNCPS calculates unavailable SC by multiplying the lignin concentration by 2.4 (22) so higher levels of lignin decreased SC availability. The MP from bacteria was reduced 8%, reducing MP allowable milk 32%. Again, rumen N balance was positive because of lower microbial growth. Because SC provides most of the energy in tropical grasses and SC digestibility is highly variable, it is important to have accurate values for NDF and lignin in tropical forages when fed as a high proportion of the diet to dual-purpose cows.

Digestion rates of carbohydrates. Predicted ME allowable milk was insensitive to changes in digestion rates of the NSC (A and B_1 ruminal carbohydrate fractions) (Table 5), because of the high intestinal digestibility (75%) assumed for these fractions. The predicted MP allowable milk increased 39% as the digestion rate of the A and B_1 fraction increased from 6 to 16%/h. The MP allowable milk increased an additional 14% as the NSC rate increased from 16 to 26%/h because more microbial protein is produced when more NSC is digested in the rumen. The ME allowable milk was very sensitive to change in the rate of digestion of the B_2 carbohydrate fraction when the NSC digestion rate was held constant at 16%/h. The ME allowable milk increased 88% when the rate increased from 3 to 6%/h, and it increased an additional 24% when the rate increased from 6 to 9%/h. The predicted MP allowable milk increased from a –0.8 to 5.7 kg/d as the B_2 rate increased from 3 to 6%/h and increased to 9.9 kg/d with a B_2 rate of 9%/h. These increases are the result of greater rumen degradation of SC.

CP and soluble protein. At a given protein solubility, as CP increased, the estimated MP allowable milk increased (Table 6) because of an increase in the MP from UIP. Less milk production was predicted when the soluble protein percentage was increased at all three percentages of CP tested (Table 6). This effect was more pronounced when CP was 12% of DM. The decrease in MP allowable milk as a result of increased protein solubility resulted from a decrease in MP from UIP. However, as more feed protein escapes the rumen undegraded, less degradable protein is available to meet microbial growth requirements, as demonstrated at the 4% CP level. Although not accounted for in the version of the CNCPS used for this study, microbial and cell wall digestion would decrease if RUP is deficient. If degradable protein equals or exceeds requirement for the carbohydrate allowable microbial growth, additional soluble protein would not be beneficial. An excess of soluble protein will increase energy requirement to excrete excess N, which would reduce energy allowable milk production.

B_3 Protein rates of degradation. Increases in the degradation rates of the B_3 protein fraction for grasses

TABLE 5. Expected milk production responses to changes in digestion rates of carbohydrates in tropical grasses[1].

	NSC[2] at 6%/h			NSC[2] at 16%/h			NSC[2] at 26%/h		
	NDF[3] 3%/h	NDF[3] 6%/h	NDF[3] 9%/h	NDF[3] 3%/h	NDF[3] 6%/h	NDF[3] 9%/h	NDF[3] 3%/h	NDF[3] 6%/h	NDF[3] 9%/h
Metabolizable energy (ME)									
Allowable milk, kg/d	4.9	9.5	11.8	5.0	9.4	11.7	4.9	9.3	11.6
ME[4] in Grass, Mcal/kg DM	1.5	1.9	2.1	1.5	1.9	2.1	1.5	1.9	2.1
MP[5] Balance, g/d	–399	–77	128	–320	2	208	–284	38	244
MP Allowable milk, kg/d	–2.4	4.1	8.3	–0.8	5.7	9.9	–0.1	6.5	10.7
Rumen N balance, g/d	85	25	–15	66	6	–34	56	–4	–44
Peptide balance, g/d	48	48	48	36	36	36	30	30	30
MP from Bacteria, g/d	334	559	708	415	640	789	452	677	826
MP from UIP[6], g/d	280	280	280	280	280	280	280	280	280

[1] The grass being evaluated was the sole dietary ingredient and intake was kept constant at 12.7 kg/d.

[2] Nonstructural carbohydrates.

[3] Available NDF.

[4] ME in grass = CNCPS predicted ME content of the grass.

[5] MP balance = metabolizable protein absorbed – metabolizable requirement.

[6] MP from UIP = the amount of metabolizable protein that is from undegradable protein intake.

decreased predicted MP allowable milk (Table 7). Less MP allowable milk was obtained at faster degradation rates because less MP was obtained from UIP. Because the rate of digestion of the B_3 protein approximated the passage rate, small changes in either the digestion rate of the B_3 protein or the predicted passage rate had a pronounced effect on the rumen degradability of the B_3 protein fraction. The B_3 protein rates in the original CNCPS library rates were much lower (generally less than 0.1%/h) than the measured rates. The original rates result in rumen escape of most of the B_3 protein (20).

Experiment 2. The Effect of N Fertilization on Carbohydrate and Protein Fractions in Tropical Grasses

The amounts and rates of digestion of the carbohydrate and protein fractions of grasses with or without N fertilization are in Table 8. The rates of digestion of the B_1 and B_2 protein fractions were not determined. The B_2 carbohydrate pool size was estimated by subtracting the lignin content * 2.4 from the NDF. This equation has been validated by Traxler et al. (22). The NSC pool size was estimated by subtraction as described by Sniffen et al. (20). In our opinion, the ME allowable milk was overpredicted for the four grasses evaluated in this experiment, particularly for *B. brizantha* and *A. gayanus* (Table 9). Because the B_2 carbohydrate fraction is the major contributor to the cow's energy supply, we thought that an overprediction of the NDF digestibility of these grasses by the CNCPS could have caused the overestimation of the ME. The range of predicted NDF digestibility was between 45 and 54%. These values for tropical grasses agree with those reported elsewhere (2, 3, 22). After it had been established that overestimation of the ME was not caused by overes-

TABLE 6. Expected milk production responses to changes in CP and soluble protein content of tropical grasses[1].

	CP at 4% in DM[2]			CP at 8% in DM[2]			CP at 12% in DM[2]		
	20% SP[3]	35% SP[3]	50% SP[3]	20% SP[3]	35% SP[3]	50% SP[3]	20% SP[3]	35% SP[3]	50% SP[3]
ME[4] allowable milk, kg	9.2	9.2	9.2	9.3	9.4	9.4	9.3	9.4	9.5
MP[5] balance, g/d	–78	–100	–122	44	2	–39	162	100	37
MP allowable milk, kg/d	4.1	3.7	3.2	6.6	5.7	4.9	9.0	7.7	6.5
Rumen N Balance, g/d	–70	–66	–63	–2	6	13	37	49	61
Peptide Balance, g/d	3	–1	–5	45	36	27	84	71	59
MP from Bacteria, g/d	683	681	680	640	640	640	594	594	594
MP from UIP[6], g/d	161	140	119	321	280	238	482	420	357

[1] The grass being evaluated was the sole dietary ingredient and was kept constant at 12.7 kg/d.

[2] Percentage of DM.

[3] Soluble protein as a percentage of CP.

[4] Metabolizable energy allowable milk production, kg/d.

[5] MP balance = metabolizable protein absorbed – metabolizable requirement.

[6] MP from UIP = the amount of metabolizable protein that is from undegradable intake protein.

TABLE 7. Expected milk production responses to changes in the rate of digestion of the B_3 protein fraction[1].

	Rate of digestion of B_3 protein[2]		
	4%[3]	7%	10%
ME[4]allowable milk, kg/d	9.4	9.4	9.4
MP[5] balance, g/d	–12	–38	–53
MP allowable milk, kg/d	5.4	4.9	4.6
Rumen N balance, g/d	7	12	14
Peptide balance, g/d	37	42	45
MP from Bacteria, g/d	640	640	640
MP from UIP[6], g/d	266	240	224

[1] The grass being evaluated was the sole dietary ingredient and intake was kept constant at 12.7 kg/d.

[2] A rate of digestion of the $B_1 + B_2$ protein fraction of 10%/h was used in this simulation.

[3] Percentage per hour.

[4] Metabolizable energy allowable milk production.

[5] MP balance = metabolizable protein absorbed – metabolizable requirement.

[6] MP from UIP = the amount of metabolizable protein that is from undegradable intake protein.

timating NDF digestibility, we evaluated the rate of digestion of the NSC (A and B_1 fractions). In the CNCPS, it is assumed that the energy yield from fermentation of NSC is constant. Doane et al. (4) indicated that this assumption is not valid, and they presented a procedure to evaluate the energy contribution of the NSC more accurately. In a recent study, Juarez Lagunes (8), using the gas production technique for in vitro digestion (19) and curve subtraction as described by Doane et al. (4) found that *A. gayanus* and *B. brizantha* produced less gas per 100 mg of NDS than *P. maximum* and *C. plectostachyus*. There are antinutritional factors in the NDS pool of some tropical forages that interfere with the NSC digestion kinetics that we did not account for. Those factors may interfere in two ways; 1) some compounds may reduce digestibility of other fractions, e.g. tannins, 2) some substrates in the NSC fraction have lower energy yields than others (e.g. organic acids) and 3) some substrates may result in higher accumulation of microbial mass (1). Compounds that may be involved include proteins (L. Belli, 1996, personal communication), silica (24), organic acids (4), tannins (17) or other compounds.

The results of the evaluation of the effects of N fertilization on the four tropical grasses are presented in

TABLE 8. Pool sizes and digestion rates of carbohydrate and protein fractions of 4 tropical grasses[1] with and without N fertilization.

	B. brizantha		*A. gayanus*		*C. plectostachyus*		*P. maximum*	
Item[2]	NF[3]	F	NF	F	NF	F	NF	F
DM, %	25.1	19.8	27.8	20.8	32.4	21.4	26.7	18.4
NDF, % of DM	69.1	63.7	71.9	67.7	78.3	71.6	71.3	66.9
Lignin, % of NDF	5.4	5.9	6.0	6.7	7.6	7.3	5.6	6.7
CP, % of DM	6.2	11.7	6.0	12.1	6.6	10.0	4.8	9.6
Solubility, % of CP	46.6	37.5	19.0	18.2	28.4	35.7	26.5	28.7
NPN, % of SolP	70.4	68.3	92.6	85.9	36.5	40.1	84.9	39.2
NDIP[2], % of CP	16.7	10.1	51.6	46.7	43.3	34.0	34.2	34.5
ADIP[2], % of CP	4.1	2.9	7.3	6.1	13.1	8.0	10.8	8.1
Fat, % of DM	1.9	2.8	1.5	2.6	1.1	1.6	2.1	3.0
Ash, % of DM	8.0	11.1	7.5	8.9	7.9	11.0	9.9	12.7
Unavailable NDF, % of DM[4]	9.0	9.0	10.4	10.9	14.3	12.5	9.6	10.8
Available NDF, % of DM[5]	59.1	53.5	58.5	51.2	61.2	55.7	60.1	52.8
NSC, % of DM[6]	15.8	11.9	16.2	14.4	9.0	9.2	13.5	11.1
Digestion rates, %/hr								
NSC (CHO A + B1)	34.0	20.0	13.2	14.4	13.1	13.2	8.9	8.3
Available NDF (CHO B2)	8.6	8.2	7.1	7.4	3.4	4.1	6.8	6.8
Available NDF protein (B3 protein)[7]	5.6	4.9	7.0	9.9	5.2	5.3	8.9	10.5

[1] *B. brizantha = Brachiaria brizantha, A. gayanus = Andropogon gayanus, C. plectostachyus = Cynodon plectostachyus*, *P. maximum = Panicum maximum* var. Guinea.

[2] NDIP = Neutral detergent insoluble protein, ADIP = acid detergent insoluble protein, CHO = carbohydrate fraction, Prot = Protein fraction.

[3] NF = Nonfertilized, F = fertilized.

[4] Unavailable NDF = NDF – (lignin % of NDF × 2.4).

[5] Available NDF = NDF – (CP *(NDFIP/100)) – unavailable NDF.

[6] NSC = nonstructural carbohydrate, and is 100 – CP – fat – ash – unavailable NDF – available NDF.

[7] Available NDF protein = NDFIP – ADFIP.

TABLE 9. Expected daily milk production responses by cows fed 4 tropical grasses with or without fertilization[1].

	Grass[2]					Fertilizer[3]		
Item	*B. brizantha*	*A. gayanus*	*C. plectostachyus*	*P. maximum*	SEM	NF	F	SEM
DMI, kg	15.5^{w}	13.7^{x}	10.6^{z}	12.4^{y}	0.12	12.6^{x}	13.5^{x}	0.08
ME[4] Allowable milk, kg	17.9^{w}	13.3^{x}	2.0^{z}	9.4^{y}	0.36	9.7^{x}	11.6^{x}	0.25
ME Available, Mcal	33.1^{w}	28.1^{x}	15.8^{z}	23.9^{y}	0.93	24.2^{y}	26.2^{x}	0.27
MP Balance[5], g/d	7^{x}	0.5^{x}	-26.5^{y}	0^{x}	2.7	-16^{x}	7^{x}	1.9
MP Allowable milk, kg	15.7^{x}	8.8^{y}	1.1^{y}	4.2^{y}	0.41	5.8^{y}	9.1^{x}	0.29
Rumen N balance, g/d	-38.7^{z}	-4.5^{y}	33.2^{x}	-4.5^{y}	3.17	-42^{y}	35^{x}	2.2
Peptide balance, g/d	24^{z}	68.2^{x}	40.2^{y}	49.5^{xy}	1.69	14^{y}	72^{x}	1.2
MP from Bacteria, g/d	951^{w}	749^{x}	380^{z}	606^{y}	11.5	699^{x}	644^{y}	8.1
MP from UIP[6], g/d	509^{x}	328^{y}	304^{y}	213^{y}	15.3	213^{x}	464^{x}	10.8

[1] The grass was the sole ingrediet in the ration.

[2] *B. brizantha* = *Brachiaria brizantha*, *A. gayanus* = *Andropogon gayanus, C. plectostachyus* = *Cynodon plectostachyus*, *P. maximum* = *Panicum maximum* var. Guinea.

[3] NF = Nonfertilized, F = fertilized.

[4] ME allowable milk = Cornell Net Carbohydrate and Protein System = predicted metabolizable energy allowable milk production.

[5] MP balance = metabolizable protein absorbed – metabolizable requirement.

[6] MP from UIP = the amount of metabolizable protein that is from undegradable intake protein.

[wxyz] Means with different superscripts differ in a row within grass ($P < 0.05$) or within fertilizer ($P < 0.10$).

Table 9. Predicted DMI was higher for *B. brizantha* than for the other grasses because *B. brizantha* had the lowest NDF and lignin contents and, therefore, the highest ME per kilogram. In the Traxler equation, predicted DMI is sensitive to NE_m content of the forage, which in turn is sensitive to the relationship between digestion and passage. The ME allowable milk was the highest for *B. brizantha* also because it had the highest B_2 carbohydrate digestion rate. This grass also had the highest predicted MP allowable milk because there was more microbial growth from fermentation of both SC and NSC, and increased MP from UIP. However, MP still limited milk production, and the supply of ruminally degraded protein did not meet microbial growth requirements (Table 9). The MP was even more limiting for the other three grasses. The ME from *A. gayanus* or *P. maximum* was predicted to support up to 9 to 13 kg of milk/d. The *C. plectostachyus* in this experiment was a low-quality grass with high NDF and lignin contents. When the cows were predicted to consume DM at 2.1% of BW, the amount of energy supplied from this grass was not adequate to support milk production.

The lower NDF was offset by higher CP and ash, which lowered the content of NSC. As a result, nitrogen fertilization did not significantly change the ME allowable milk. However, it improved the MP allowable milk dramatically (Table 9). Because N fertilization increased both the CP and soluble protein content of the grasses, both the ruminal N balance and the peptide balance increased. We conclude N fertilization can be expected to improve MP allowable milk, primarily because of increased pool sizes of CP and soluble protein. These results need to be evaluated with other species, stages of maturity, N fertilization levels, soil, and growing conditions.

CNCPS Predictions with Data from Dual-Purpose Cows and Measured and Tabular Feed Values

Those using the CNCPS often use the feed composition values in its feed library to evaluate diets and develop feeding programs. To compare the effects of using tabular or measured carbohydrate and protein fractions and rates of digestion, we used the data from the dual-purpose cows described in Tables 1 and 2 and the actual diets fed to these cows (Table 10). We evaluated the DMI predicted by the CNCPS to support the observed performance, using both the tabular and measured feed data. The modeling assumptions and inputs used are outlined below.

Simulation inputs and assumptions. Animal and environment inputs (Table 2) describe a mature, mid-lactation, crossbred cow (¾ Holstein × ¼ Zebu) in August. The cows were milked mechanically twice daily and calves were not allowed to suckle. Daily milk production and monthly analyses of fat, protein, and SNF were used to calculate biweekly measurements of milk production and composition for individual cows (12). Monthly BW was recorded. Changes in BW were calculated as the BW of the current month minus the BW of the previous month. The month of August was chosen because it is the middle of the rainy season and forage availability does not limit voluntary DMI. The environmental temperature and wind speed were recorded daily and pooled monthly by the meteorological station in Veracruz (Centro de Prevision del Golfo) located 20 km from the National Institute of Agroforestry and Animal Science Research experiment station.

The animal data were from cows that rotationally grazed 27 ha of Pangola grass (*Digitaria decumbens*). The grazing plots were 1 ha each with cows grazing one plot each day. The regrowth of plots was allowed for 27 d between grazing periods. Cows were fed 3.5 kg of concentrates daily. Two kilograms were offered in the morning and 1.5 kg were fed in the afternoon. The concentrate mix (DM basis) contained 64% sorghum, 22% soybean meal, 10% cane molasses, 3% mineral mixture, and 1% urea.

Simulation results. Samples of Pangola grass (*Digitaria decumbens*) were collected during August at 28 d of regrowth. These forage samples along with samples of the ingredients included in the concentrate were freeze-dried and sent to Cornell University for analysis, as described in Experiment 1.

Because the DMI of the pasture was unknown, a common situation in grazing studies, we computed DMI requirements from the observed performance (CNCPS with tabular or measured pool sizes and digestion rates) as described by Perry and Fox (16). Pasture intake was changed until the predicted and observed energy balance (**EB**) (computed from BW, milk production, and daily BW gain or loss) agreed. We assumed 1 kg of BW gain or loss contains 5.82 Mcal reserves energy (13).

The results of the chemical and in vitro digestion analyses for Pangola grass and the ingredients included in the concentrate are presented in Table 10, along with tabular values. Most of the measured carbohydrate and protein pool sizes for Pangola grass are similar to the tabular values, except that the measured NPN value was considerably higher than the tabular value. The starch as a proportion of the NSC was higher because the original tabular value was erroneously entered as a percentage of DM instead of as a percentage of NSC. Measured digestion rates for NDS ($A + B_1$ carbohydrate fractions) were lower than the tabular values, but the measured digestion rates for the B_2 carbohydrate and B_3 protein fractions were higher. The digestion rates for the B_1 and B_2 protein fractions were not measured.

The average EB was positive as was evident by a daily BW gain of 0.42 kg (Table 1). The calculations to evaluate the EB were as follows:

TABLE 10. Feed analysis used for evaluating cattle performance with the CNCPS.

Item	*D. decumbens*[1,2]	*D. decumbens*[3]	Sorghum grain[3]	Soybean meal[3]	Cane molasses[3]
DM, %	21.0	26.8	87.4	89.0	85.8
NDF, % of DM	70.0	69.5	10.3	11.4	0.0
Lignin, % of NDF	11.4	7.5	12.8	0.9	0.0
CP, % of DM	9.1	8.9	10.4	52.6	4.2
Solubility, % of CP	42.0	41.9	14.9	16.0	98.0
NPN, % of SolP	4.8	36.3	33.0	55.0	100.0
NDIP[4], % of CP	24.0	32.5	33.9	5.5	0.0
ADIP[5], % of CP	2.2	5.4	5.0	2.0	0.0
Fat, % of DM	2.3	2.4	3.6	2.0	2.2
Ash, % of DM	7.6	8.6	3.0	7.0	11.6
Unavailable NDF, % of DM[6]	19.2	12.5	3.2	0.3	0
Available NDF, % of DM[7]	48.7	54.1	3.6	8.3	0
NSC, % of DM[8]	13.2	13.5	76.2	29.9	82.0
Digestion rates, %/hr					
NSC (CHO A + B1)	30.0	19.7	14.3	7.9	17.5
Available NDF (CHO B2)	3.0	5.3	6.0	5.7	
B1 protein	135.0	…	135.0[2]	230.0[2]	350.0[2]
B2 protein	11.0	…	6.0[2]	11.0[2]	11.0[2]
Available NDF protein (B3 protein)[9]	0.09	5.3	0.12[2]	0.20[2]	0.25[2]

[1] *Digitaria decumbens*.

[2] Tabular values, 1996 National Research Council Nutrient Requirements of Beef Cattle.

[3] Laboratory measurements except where noted.

[4] Neutral detergent insoluble protein.

[5] Acid detergent insoluble protein.

[6] Unavailable NDF = NDF – (lignin % of NDF × 2.4).

[7] Available NDF = NDF – (CP * (NDFIP/100)) – unavailable NDF.

[8] NSC = nonstructural carbohydrate, and is 100 – CP – fat – ash – unavailable NDF – available NDF.

[9] Available NDF protein = NDFIP – ADFIP.

TABLE 11. Evaluation of performance of dual purpose cows with the Cornell Net Carbohydrate and Protein System (CNCPS) with either tabular or measured feed values.

Item	CNCPS with feed library composition	CNCPS with measured feed composition
	kg DM/d	
Diet ingredients		
Sorghum grain	2.24	2.24
Soybean meal	0.77	0.77
Molasses cane	0.35	0.35
Minerals	0.10	0.10
Urea	0.04	0.04
D. decumbens[1,2]	14.3	9.05
Total	17.7	12.6
MP balance, g/d	–67	65

[1] *Digitaria decumbens*.

[2] DMI required to sustain observed performance.

[3] Protein that is from UIP.MP balance = metabolizable protein absorbed – metabolizable requirement.

1 kg of BW = 5.82 Mcal of reserves energy (13),
$0.42 \times 5.82 = 2.5$ Mcal of daily reserves energy gain,
1 Mcal of ME = 0.75 Mcal of energy in reserves (7),
$2.5/0.75 = 3.3$ Mcal of ME/d.

Thus to compute the DMI required to support the observed ADG in each evaluation, the pasture intake was changed until a balance of 3.3 Mcal of ME was obtained.

Predicted DMI requirements, with the tabular and measured feed values, are presented in Table 11. When the CNCPS was used with the tabular feed values, the DMI required was 40% higher than when measured feed composition values were used. The DMI predicted with the equation of Traxler (21) that was developed with dairy cows fed tropical forages was nearly identical to the CNCPS predicted amount of DMI needed to support the observed animal performance (12.6 vs 12.5 kg) when actual forage composition and measured digestion rates were used. We conclude that the CNCPS predicted animal requirements and the nutritive values of the feeds well in this situation when measured feed composition values were used. The predicted MP supply was 65 g greater than that required for the energy allowable milk production in this situation, suggesting the cows produced milk at the level the ME intake would allow. The 67-g deficiency of MP predicted by the CNCPS with tabular feed composition values indicates milk production would have been limited to less than that observed. Although measured and tabular NDF values were nearly identical, the lower concentration of lignin and the higher rate of available fiber digestion resulted in a higher predicted ruminal degradation of fiber which results in higher microbial yield and higher ME value for the grass.

CONCLUSIONS

The results presented show variations in feed carbohydrate and protein fractions and their digestion rates in tropical grasses can have a large effect on milk production of dual-purpose cattle. In these evaluations, we assumed the CNCPS accurately predicted animal responses to these variations in feed composition, based on previous studies (10). In those studies, the CNCPS as described in this paper was evaluated at the University of Sao Paulo at Piracaba (Brazil) for accuracy of predictions in tropical conditions with actual DM intake of tropical feeds fed to cattle types typical of those used in the tropics (10). Feeds were characterized for their content of carbohydrate and protein fractions and their digestion rates. The energy and protein content of empty BW gain (growing animals) and milk production (dual-purpose lactating cows) were measured. The growing cattle data set included 943 Nellore (the most common Zebu breed in Brazil) bulls and steers fed 96 different diets, with a subset of approximately 200 head used to determine composition of weight gain. Average live weight and live weight gain were 337 kg and 0.923 kg/d, respectively. The CNCPS accounted for 72% of the variation in live weight gain with only a 2% bias. The lactating cow data set included 18 different diets fed to 178 Zebu crossbred cows representing the wide range in genotypes used for milk production in tropical conditions. The CNCPS accounted for 71% of the variation in milk production with a 10% bias. The 10% bias for the lactating cows is believed to be due to difficulty establishing the maintenance requirements of the animals because of the wide variation in their percentage of Holstein and Zebu. The authors observed that accounting for more of the variation in performance with the CNCPS would be difficult, because of the lack of uniformity in genotype within Zebu cattle. The authors (10) concluded that the CNCPS was more accurate than the NRC under tropical conditions when the feeds and cattle types could be characterized adequately to provide accurate inputs into the CNCPS. The CNCPS then should provide a more precise and dynamic estimate of nutrient requirements and animal performance.

Based on these evaluations, we conclude the CNCPS can be used to describe animal requirements and the biological values of tropical feeds for cattle typical of those kept in the tropics for developing feeding recommendations, if adequate forage analysis information is available. With tropical grasses, predictions of animal responses are highly dependent on accurate values for NDF, lignin, CP and soluble protein and rates of digestion for the B_2 carbohydrate and B_3 protein fractions.

IMPLICATIONS

With adequate feed composition and rates of digestion values and with accurate environmental and animal descriptions, the CNCPS can be used to predict the ME and MP of grasses for dual-purpose cows in semihumid areas in the tropics, which can be used in developing more accurate feeding programs.

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