PROTEIN/IONOPHORE SUPPLEMENTATION OF GRAZING CATTLE

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INTRODUCTION

Ruminants require dietary intake protein (IP) for the nutrition of two sequential ecosystems; firstly the rumen microbial ecosystem and secondly the ruminants' tissues *per se*. In ruminal digesta, a portion of intake protein is degraded (DIP) to provide the ammonia, amino acid and other precursors required for growth of the ruminal microbial ecosystem. Intake protein undegraded in the rumen (UIP) flows to the intestines where digestion of UIP and rumen microbes collectively provides the metabolizable amino acids required by the ruminants' tissues.

With an adequate supply of precursors, the growth rate of the rumen microbial ecosystem is determined via the flux of energy derived from ruminal fermentation of dietary carbohydrates. In contrast, the rate of degradation of intake protein to DIP is a characteristic of the feed and frequently results in release of DIP in excess of that required based on the energy limited growth rate of the rumen microbial ecosystem. When genesis of DIP exceeds the DIP required for the energy limited growth of the microbial ecosystem, the resulting ammonia is essentially in-nutritious for the ruminant's tissues. Thus, conversion of intake protein to DIP in excess of energy limited capacity of the microbial ecosystem to use DIP is a major source of inefficiency in ruminant nitrogen utilization.

Ingested proteins of actively growing forages are characteristically very rapidly degraded relative to the rate of fermentation of carbohydrates and, consequently, are inefficiently used. Some ionophores have the ability to suppress ruminal degradation of intake proteins and such a mode of action could result in beneficial interactions in productive ruminants grazing rapidly growing forages, the object of this review.

RESULTS

Ruminant nitrogen utilization. According to the NRC nitrogen usage model (1985), a 250 kg, large frame calf gaining one kg/d requires 5.6 kg/d of feed DM containing 2.35 mcal of metabolizable energy (ME) per kg to provide for the energy requirements of the calf. The fermentable energy yield from this quantity of feed will support a microbial growth rate which requires 355 g/d of DIP to provide dietary nitrogen precursors (table 1). For maintenance of the 250 kg calf and support of a gain of one kg/d, the calf requires a total flux to the intestines of 683 g/d of protein. Therefore, an additional quantity of 327 g/d of dietary UIP is required to supplement the 355 g/d of DIP required for microbial protein synthesis. Thus in the 5.6 kg/d of feed, the calf requires 683 g/d of intake protein (IP) specifically as 355 g/d of DIP and 327 g/d as UIP. Alternatively, this can be stated as a requirement for 12.2% IP with a ruminal undegradability (UIP/IP) of .48 and a ruminal degradability of .52.

The undegradability of actively growing forages is considerably less than .48, typically in the order of .2 (Beever and Siddons, 1984; Cruickshank et al., 1992; Hill 1991). As indicated in table 1, forages containing .2 UIP would need to contain considerably more IP (.292 IP/DM) than such forages commonly contain in order to provide sufficient daily quantity of UIP. Such nutritional insufficiencies in UIP from growing forages is demonstrated by growth responses to protein infused into the abomasum of young lambs grazing clover pastures containing very high levels of IP (30% IP, Fraser et al., 1990, 1992).

Some specific estimates of undegradability of the proteins of grazed forage and supplemental proteins are summarized in table 2. Undegradability was estimated by Hill (1991) via both *in vivo* and a combination *in situ* and *in vivo*

Table 1. Requirements[a] for a 250 kg calf gaining one kg/d for ruminally degraded intake protein (DIP) and undegraded intake protein (UIP) and dietary requirements for UIP and intake protein (IP) in grazed forages of different ruminal undegradability (UIP/IP).

Requirements by calf, g/d or (fraction of IP):

DM	DIP	UIP	IP	IP/DM
5,600	355 (.52)	327 (.48)	683 (1.0)	.122

Dietary intake required to provide UIP requirements of calf:

UIP/IP	DIP	UIP	IP	IP/DM
0.52	355	327	683	.122
0.4	490	327	817	.146
0.3	763	327	1,090	.195
0.2	1,308	327	1,635	.292
0.15	1,853	327	2,180	.389

[a] According to NRC, 1985

Table 2. Fractional rates of degradation[a] (k_d), passage[b] (k_p) and escape[c] (UIP/IP) of some proteins when supplemented to calves grazing bermudagrass[d] or ryegrass[e] pastures (From Hill, 1991).

Protein	Bermudagrass[f]			Ryegrass[g]		
	k_d	k_p	UIP/IP	k_d	k_p	UIP/IP
Bermudagrass	.023	.027	.49[h]	-	-	-
Ryegrass	-	-	-	.244	.056	.14
Blood meal, ring dried	-	-	-	.056	.118	.63
Corn, ground	.042	.031	.35	.055	.092	.49
Cotton seed meal, sol.	.053	.029	.28	.055	.092	.49
Feather meal, hydrol.	.021	.034	.52	.029	.122	.70
Menhaden fish meal[i]	.044	.032	.39	.070	.124	.59

[a] fractional rate of degradation *in situ* in rumen of steer on hay diet
[b] fractional rate of passage of rare earth labelled supplement introduced into rumen of grazing test calves
[c] fractional rate of escape of supplemental protein to duodenum
[d] Esophageal extrusa OM: 74% NDF, 7.6% CP and 53% OMD
[e] Esophageal extrusa OM: 37%NDF, 20.5% CP and 65% OMD
[f] N=2
[g] N=3
[h] late season, heavy seeded, common bermudagrass
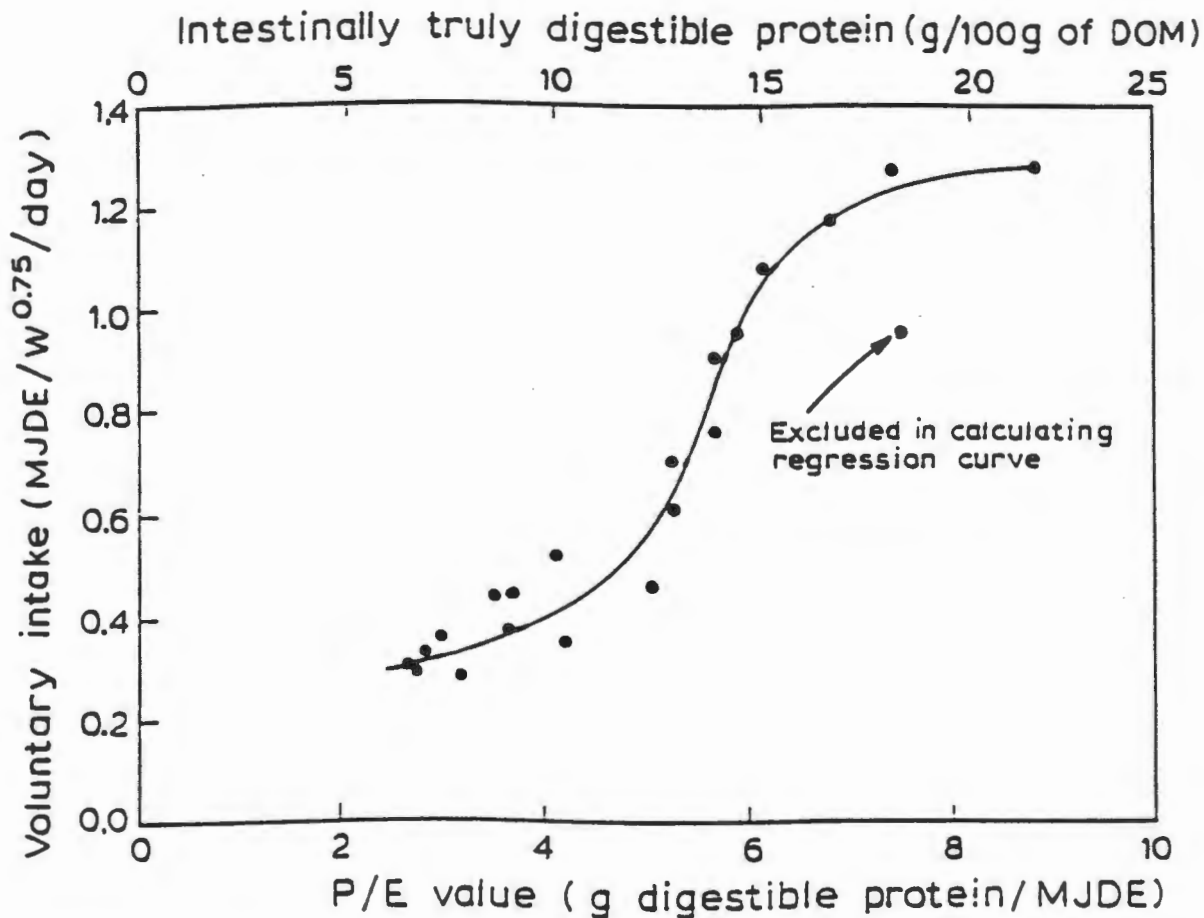[i] "Sea-lac", ruminant grade Menhaden fish meal, Zapata Proteins, Hammond Louisiana

Figure 1. Effects of altering the flux of intestinally truly digestible protein by abomasal infusion of protein into sheep upon altered ratio of truly digested protein / digested energy ratio (modified from Egan, 1977).

methods and agreement between methods were excellent (Ellis et al., 1994). Several points should be noted in the data of Hill. Firstly, the undegradability of protein in a given supplemental protein feed is not constant when used to supplement different grazed forages. This difference is primarily attributed to slower rates of passage (or conversely larger loads of ruminal digesta) for the less digestible warm season as compared to the more digestible cool season forages. Thus considerable errors in estimation of UIP/IP will result if a universal rate of passage of the test protein is assumed as commonly done for *in situ* estimates of rate of protein degradation. Secondly, the ruminal rate of passage of the protein concentrate differs from other feed particles (and also for solute markers, Cabello et al., 1990) and must therefore be specifically estimated. Most estimates of undegradability of protein have been estimated in concentrate fed animals and the value for rate of passage may, therefore, have little relevance for grazing animals.

Ruminal utilization of proteins ingested as grazed forage. Estimates of undegradability of the proteins of grazed ryegrass in table 2 (.15) are consistent with values summarized by Beever and Siddons (1984) for proteins of actively growing forages on ingestion via grazing. Extensive ruminal degradation of proteins of grazed forage appears associated with the rapid transition which occurs when active plant metabolism of the ingestively masticated forage fragments is

Table 3. Effects of supplements containing mineral (basal), fish meal (fish) or feather meal (feather) upon forage intake (% of BW) and body weight gain (kg/d) of calves (mean BW = 102 kg) grazing bermudagrass (14 % CP in esophageal sample).

Item	Supplement			
	None	Basal	Fish	Feather
Number of calves	6	7	6	5
Period 1 (21 days)				
Daily forage intake	-	2.0[a]	2.2[b]	2.0[a]
Daily gain	0.20[a]	0.34[a]	0.76[b]	0.60[b]
Period 2 (21 days)				
Daily forage intake	-	2.7[a]	2.5[a]	2.1[b]
Daily gain	0.84[a]	0.83[a]	0.90[a]	0.76[b]
Period 3				
Daily forage intake	-	2.3[a]	2.2[a]	1.9[b]
Daily gain (periods 1&2)	0.52a	0.59[a]	0.83[b]	0.68[c]

[a,b,c] Means with unlike superscripts differ, P = < 0.05.

transposed to and interacts with the ruminal environment. For example, proteins of ryegrass and clover are more extensively degraded when ingested as grazed than when ingested as harvested and frozen and least degraded when ingested as harvested and dried at progressively greater temperatures (Beever et al., 1986, 1987 and Beever and Siddons, 1994) .

The value for undegradability of grazed bermudagrass in table 2 appears large compared to the generalizations indicated by the summary of Beever and Siddons (1984). The relatively undegradable nature of this particular sample may be due to the heavy seed production of the common variety of bermudagrass and different rates of digestion and passage and digestion of seed *vs.* forage proteins. As will be discussed, indirect evidence indicates that the protein of grazed hybrid varieties of bermudagrass such as "Coastal" is more extensively degraded than 0.49.

Effects of supplemental metabolizable protein. A primary effect of supplemental metabolizable protein (MP) is its positive effects upon forage intake. This is best illustrated by the data of Egan (1977) reproduced in Figure 1. Although depicted as a curvilinear relationship in

figure 1, this relationship did not significantly differ statistically from being linear over the range studied. Such a linear relationship over the wide range of the data indicates considerable latitudes for intake responses as the ratio of MP to ME increases in sheep fed harvested forages.

Effects of amino acid balance. The ruminant has the same qualitative requirement for dietary indispensable amino acids as do mammals in general. Also, as in other mammals, imbalances in metabolizable amino acids adversely affects feed intake (Egan and Rogers, 1978). Recent results by Hill (1991) suggest that the balance of amino acids in the flux of metabolizable amino acids has significant effects on grazed forage intake. The experiments of Hill involved growing calves with ruminal and duodenal cannulae grazing bermudagrass or ryegrass pastures and receiving supplements containing the protein sources indicated in table 2, together with 100 mg/d of Lasalocid. Fecal output and duodenal flow was estimated by reference to rare earths constantly infused into the rumen and flow of intestinal protein was partitioned into microbial protein using ^{35}S, also constantly infused into the rumen. Ruminal digestibility was determined by reference to indigestible fiber as an indigestible

Figure 2. Some relationships between voluntary intake of bermudagrass (solid regression line) and ryegrass (dashed regression line) and ruminal utilization in calves receiving no supplements (R=ryegrass) supplements of corn (Z) or isonitrogenous supplements containing cottonseed meal (C), menhaden fish meal (M), blood meal (B), feather meal (F) or a condensed molasses-cottonseed meal block (Q).

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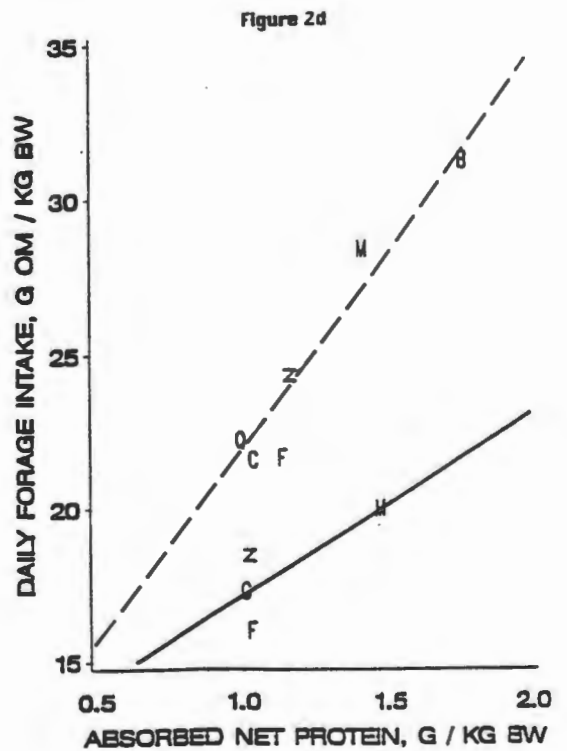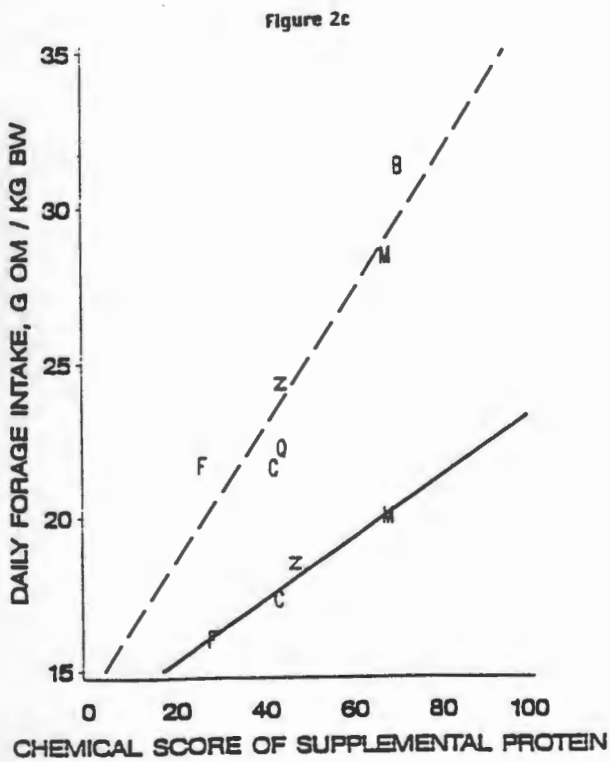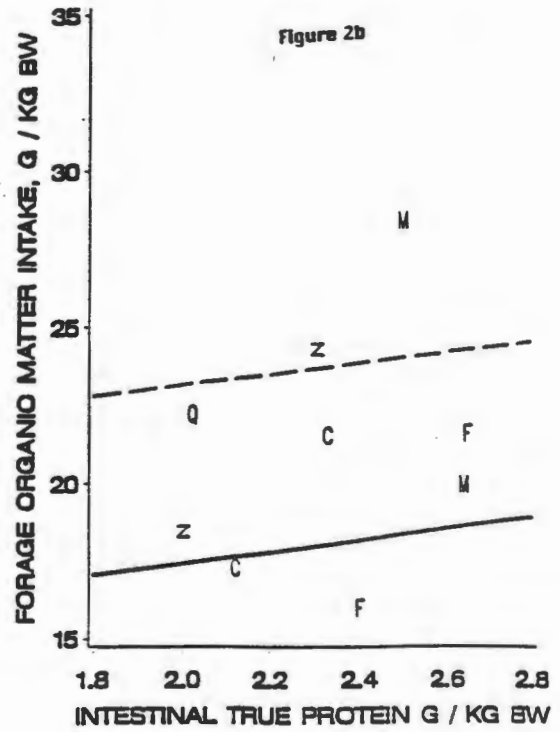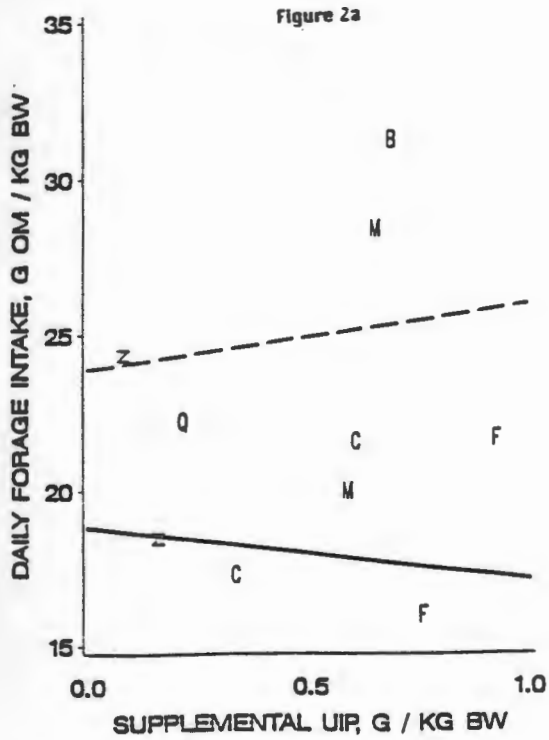
internal marker. Published values for amino acid composition of the protein supplements and microbial protein was used and equal intestinal digestibility of each amino acid was assumed.

In the experiments of Hill (1991) source of supplemental protein had no effect on digestibility of fiber or efficiency of microbial protein synthesis. The major effects of source of supplemental protein were upon flow of true protein to the intestines and grazed forage intake. Some of the main results of Hill (1991) are summarized in figure 2. Results in figure 2A indicate that variations in flux of UIP from the different sources of supplemental proteins was not significantly (P > 0.05) related to variations in grazed forage intake. Similarly , variations in flux of estimated digestible protein from the supplement plus the forage were not significantly (P > 0.05) related to variations in grazed forage intake (figure 2B). Variations in intake of grazed forage was significantly (P = 0.05), positively related to the amino acid balance of the supplement when the amino acid balance was expressed as a chemical score (figure 2C). The chemical score expresses the limiting indispensable amino acid of the test protein relative to whole egg protein. The chemical score expresses an estimate of the biological value or net protein value of the mixture of amino acids from the test mixture of amino acids.

The flux of net protein was calculated from the intestinal flux of UIP from forage, from supplement and from microbial true protein, assuming a true digestibility of 0.9, 0.9 and 0.8 respectively. Published values were used for the amino acid composition of each source of protein and a uniform true digestibility of 0.9 assumed for each amino acid. Variations in grazed forage intake was significantly (P = < 0.05) related to the estimated flux of total net protein (figure 2D).

Results of a trial involving lightweight calves supports an effect of amino acid balance upon intake of grazed bermudagrass and liveweight gains (table 3). However, results of a larger scale growth trial (table 4) do not support an effect of amino acid composition of the supplement on performance of calves grazing bermudagrass.

Efficiency of microbial protein synthesis. The efficiency of transforming fermented energy into rumen microbial protein is an important transformation in determining overall efficiency of ruminant nitrogen utilization. This efficiency is usually expressed as units of microbial protein fluxing from the ruminant's gastric sections per unit of truly fermented energy in the gastric sections. In the experiments of Hill (1991), source of supplementary protein had no effect on true digestion of organic matter (**OM**) or potentially digestible neutral detergent fiber (**NDF**) in the gastric sections and levels of ruminal ammonia indicated sufficient concentrations of ammonia (> 10 mg NH_3 per 100 ml and > 20 mg NH_3 per 100 ml for bermudagrass and ryegrass experiments respectively) such that DIP did not limit efficiency of microbial protein synthesis.

Mean efficiencies of ruminal microbial efficiency observed by Hill (1991) are summarized in table 5 and compared to efficiencies assumed

Table 4. Mean[a] performance of steers (mean BW=213 kg) grazing "Coastal" bermudagrass pastures and receiving various supplements (Rouquette, et al., 1993).

Item	Supplement		
	Mineral	Fish meal[b]	Feather meal[c]
Average daily gain, kg/d	0.53	0.71	0.85
Average daily supp., kg/d	?	0.568	0.568
Increased gain, IG, kg/d	-	0.18	0.32
Average daily supp/IG	-	3.1	1.8

[a] Mean of two replicates per treatment of 12 steers per replicate
[b] 36% CP, 1.7% phosphorus; hand fed daily
[c] 36% CP, 1.7% phosphorus; hand fed daily

Table 5. Mean efficiency of ruminal microbial protein synthesis (g true microbial protein appearing in duodenum per 100 g organic matter truly digested in rumen) in calves grazing different pastures. Observed and expected via different models.

Item	Grazed forage		
	Bermudagrass	Ryegrass 1	Ryegrass 2
Observed, Hill, 1991	15.9 ± 1.3	6.44 ± 0.9	9.5 ± 0.7
NRC, 1985	$\approx 10.6^a$	$\approx 13.05^b$	$\approx 13.05^b$
CNCNP system, 1991	$\approx 5\text{-}15^c$	$\approx 15\text{-}25^d$	$\approx 15\text{-}25^d$

[a] Assuming 53% DOM observed = 53% TDN, 26.1 g microbial CP nitrogen synthesized per kg TDN, .65 of truly digestible OM digested via fermentation, and bacterial CP = .8 bacterial true protein
[b] As for [a] except assuming 63% observed DOM = 63% TDN
[c] Estimated by extrapolation from figure 1 of Russell et al., 1991 using observed turnover of forage residues ($k_p = .027^{-h}$) to duodenum to reflect microbial growth rate. The lower estimate and upper estimates are for microbial population digesting 100% structural and 100% nonstructural carbohydrates respectively
[d] As for [c] except for $k_p = .056^{-h}$

by various models. Efficiency of rumen microbial protein synthesis in calves grazing ryegrass was relatively small (6-10%) as compared to calves grazing bermudagrass pastures. The relatively low efficiency observed for ryegrass in these experiments is similar to that reported by Beever and Siddon (1984) for grazed ryegrass and contrasts to efficiencies in the order of 20-23% reported for fresh harvested or dried ryegrass (Beever et al., 1986). Thus it appears that

extensive ruminal degradation of proteins of ryegrass ingested via grazing, and other temperate forages such as clovers, is also associated with inefficient conversion of DIP to microbial protein. Beever and Siddons (1984) suggest that this inefficient transformation to microbial protein is the result of poor synchronization between rate of release of ammonia and rate of genesis of fermentable energy in grazing animals.

Table 6. Summary of performance of calves grazing bermudagrass pastures and supplemented with either a free choice mineral (Mineral) or a 32 % protein supplement containing 45 mg of Monensin per kg of supplement (supp.)

Trial	Average Daily Gain		Extra Gain over mineral control	Daily Supp.	Supp./ extra gain
	Mineral Supp.	Protein-monensin Supp.			
	---------------- kg/day----------------		kg/kg	kg	kg/kg
1	0.68	0.97^a	0.29	1.42	2.0
2	0.47	0.90^a	0.44	0.55	1.24
3	0.38	0.69^a	0.30	0.45	1.49
4	0.38	0.69^a	0.29	0.42	1.43
5	0.29	0.60^a	0.31	0.52	1.67
6	0.36	0.75^a	0.39	0.61	1.57
7	0.36	0.60^a	0.20	0.61	3.00
8	0.53	0.71^a	0.19	0.57	2.98
9	0.53	0.65^a	0.20	0.57	2.91
Means	0.44	0.73^a	0.29	0.54	2.02

[a] Differs (P < 0.05) from the average daily gain by animals receiving the corresponding mineral control.

Table 7. Effects of supplements with and without monensin (M, 45 mg/kg.) on performance of heifers (ADG) grazing bermudagrass pastures.

Supplement	Average daily gain (ADG)	Increase in ADG over mineral ADG (IG)		Supplemental efficiency: kg.supplement per kg. IG
	kg	kg	%	kg/kg
Mineral	0.60[c]	0.0	(00)	0.0
8% CP	0.72[b]	0.11	(19)	12.3
8% CP + M	0.71[b]	0.10	(16)	12.9
32% CP	0.83[a]	0.22	(37)	4.6
32% CP + M	0.92[a]	0.31	(52)	3.2

[a,b,c] Means with different superscripts differ, $P < 0.05$.

The NRC system (1985) can be criticized as being a static system in which a constant 26.1 g of microbial crude protein is assumed to be synthesized per kg of total digestible nutrients (TDN) consumed. The Cornell Net Carbohydrate and Protein System (CNCPS) has the theoretical advantages of being based on rates of carbohydrate and protein degradation and estimating efficiency of microbial protein synthesis as a function of microbial growth rate (Russell, et al., 1992). However, it is apparent that neither system accounts for the relative low efficiency of microbial protein synthesis in the presence of excessive levels of DIP. Thus it is apparent that data on ruminal utilization of dietary protein in ruminants fed conserved feeds may not be applicable to the grazing animals.

Enhancing efficiency of grazed forage utilization: warm season forages. Agents to enhance efficiency of overall utilization of forage ingested via grazing are obviOvertonously desirable. The ionophore Monensin appears to improve efficiency of nitrogen utilization primarily by suppressing growth of microbes which ferment amino acids as a source of energy (Russell et al., 1991 and Yang and Russell, 1993). Supplements of corn and a quality protein (fish meal) containing 100 mg of Monensin/lb have proven very effective in increasing gain by steers grazing "Coastal" bermudagrass pastures. Results of nine trials conducted at Overton, Texas are summarized in table 6.

The responses due to protein/Monensin supplementation summarized in table 6 are considerable larger than expected when Monensin is supplemented in an energy based supplement to calves grazing such pastures (0.1 to .2 kg/d). Results of an additional experiment (table 7) indicate that a greater response to Monensin occurs in a 32% vs. an 8% CP supplement and that approximately 70% of the gain response in the high protein-Monensin supplement appears due to the supplemental protein. Effects of the protein and combination protein-Monensin supplements upon reducing the units of supplement per unit of gain response (supplemental efficiency) was the result of supplemental protein either increasing forage intake or the efficiency of utilization of forage protein. Such increases in supplemental efficiency could arise due to increased efficiency of ruminal utilization of forage protein or increased flux of metabolizable protein and consequent increased intake of grazed forage.

Deficiency of UIP in "Coastal" bermudagrass ingested via grazing. Using the NRC model and the observed performance of calves grazing "coastal" bermudagrass (Tables 6 & 7) estimates can be derived for the utilization of IP and the magnitude of the the deficiency of dietary UIP. Samples of the bermudagrass pastures involved in the results summarized in tables 6 & 7 typically contained 10-12% IP. This amount of IP is in the order of nutritional adequacy if its ruminal undegradability is 0.57 or

Table 8. Requirements[a] for a 250 kg calf to gain 700 g/d for ruminally degraded intake protein (DIP) and undegraded intake protein (UIP) and dietary deficiency of UIP in grazed forages of different ruminal undegradability (UIP/IP).

Requirement by calf, g/d:

DM	DIP	UIP	IP	IP/DM
5,600	265	351	616	.11

Intake of DIP and UIP (g/d) from forages containing 11% IP and different ruminal undegradability, UIP/IP:

UIP/IP	DIP	UIP	IP	UIP deficiency
0.57	265	351	616	0
0.4	369	246	616	-105
0.3	431	185	616	-166
0.2	493	123	616	-228
0.15	524	92	616	-259

[a] According to NRC, 1985

greater. The performance response of the calves to 60-118 g/d of supplemental UIP (tables 6 & 7) suggest that the proteins of "Coastal" bermudagrass ingested via grazing in these experiments had a ruminal undegradability of 0.4 and resulted in a deficiency in the order of 105 g/d of UIP. If verified, this undegradability for "Coastal" bermudagrass ingested via grazing appears larger than generally reported for warm season perrenials ingested via grazing (Beever and Siddons, 1984). The NRC system appears to provide reasonable estimates of performance of growing calves grazing bermudagrass pastures provided that the IP and UIP/IP of the ingested forage is known.

Enhancing efficiency of grazed forage utilization: ryegrass. Ryegrass forage is very palatable and voluntary consumption of protein supplements is difficult to achieve except in late season growth. In contrast, voluntary consumption of corn based - ionophore supplements can more readily be achieved. Results of several years of studies at Overton involving corn-Monensin supplementation are summarized in table 9. The consistent effect of limited daily intake (< 0.7 kg/head) of the corn-Monensin supplement has been to increase average daily gains by 0.32 kg/d with a supplemental efficiency of 2.1. The results in table 9 conform

to expectations from earlier results (tables 1 and 2) that such pastures would be deficient in UIP. However, the mechanism whereby such a limited amount of corn-Monensin would increase flux of metabolizable protein is unclear. Based on only two trials (table 10), effects on gain and supplemental efficiency of corn-ionophore are greater than obtained from protein-monensin and suggest that small amounts of starch improve synchronization of overall protein-carbohydrate utilization. It is tempting to speculate a beneficial effect of Monensin upon further improving efficiency of microbial protein synthesis, however Beever et al., 1987 has specifically demonstrated that Monensin did not affect the efficiency of this transformation.

CONCLUSIONS

Due to extensive (80 to 90%) ruminal degradation of the proteins ingested via grazing actively growing forages, deficiencies of UIP appear to limit performance of productive ruminants regardless of the level of CP in the forage. As compared to mineral supplementation, supplemention with mineral-, protein- or corn-Monensin supplements will increase gains by calves in the order of 0.3 kg/d. Supplements containing 30+% of a quality CP source(s) and 45 mg of Monensin/kg are recommended for calves grazing

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Table 9. Summary of performance of calves receiving a free-choice corn-monensin or mineral supplement while grazing ryegrass pastures at Overton Texas (five experiments, five years, 166 head averaging 295 kg initial weight).

Expt.	Average daily Gain (ADG), kg/d		ADG supp.- ADG min. (IG)		kg corn-monensin / d
	Minerals	Corn + Monensin	kg. IG / d	kg supp / kg IG	
1	0.87	1.04	0.17	1.9	0.34
2	1.00	1.58	0.57	1.3	0.76
3	1.00	1.48	0.48	1.6	0.73
4	1.09	1.26	0.17	3.1	0.51
5	0.99	1.20	0.20	2.9	0.60
Means: ADG IG,%	0.99 -	1.31 32%	0.32 32%	2.1 -	0.59 -

warm season grasses and can be expected to require approximately 2-2.5 kg of supplement per kg of additional gain. Supplements of corn with 45 mg of Monensin/kg fed at a daily rate of one

kg/head are recommended for calves grazing cool season grasses and similarly can be expected to require approximately 2-2.5 kg of supplement per kg of additional gain.

Table 10. Performance of calves receiving various supplements while grazing ryegrass pastures.

Experiment	Average Daily Gain, kg/d		
	mineral	corn + monensin	38% protein + monensin
1	1.00	1.58	1.19
2	1.09	1.26	1.15
Mean ADG	1.05	1.42	1.17
Mean ADG for monensin supp. Mean ADG for mineral supp.	-	35%	11%

LITERATURE CITED

Beever, D. C. and R.C. Siddons. 1984. Digestion and metabolism in the grazing ruminant. *In* Control of Digestion and Metabolism in the Grazing Ruminant. L. P. Milligan, W. C. Grovum and A. Dobson (Ed.) Prentice-Hall, Englewood Cliffs, NJ.

Beever, D. C., M. S. Dhanoa, H. R. Losada, R. T. Evans. S. B. Bammell and J. France. 1986. The effect of forage specie and stage of harvest on the processes of digestion occurring in the rumen of cattle. Brit. J. Nutr. 56:439.

Beever, D. E., H. R. Losada, D. L. Gale, M. C. Spooner and M.S. Dhanoa. 1987. The use of Monensin or formaldehyde to control the digestion of the nitrogenous constituents of perennial ryegrass (Lolium perenne cv. Mele) and white clover (trifolium repens cv. Blanca) in the rumen of catle. Brit. J. Nutr. 57:57.

Cabello, L., T. M. Hill, S. D. Martin, and W. C. Ellis. 1990. Ruminal escape turnover of unfermented residue of grazed bermudagrass and supplements in calves. J. Anim. Sci. 70 (Supple. 1):188.

Cruickshank, G. J., D. P. Poppi and A. R. Sykes. 1992. The intake, digestion, and protein degradation of grazed forage by early weaned lambs. Brit. J. Nutr. 68:349-364.

Egan, A.R. 1977. Nutritional status and intake regulation in sheep. VIII. Relationships between voluntary intake of herbage by sheep and the protein calorie ration in the products of digestion. Aust. J. Agric. Res. 28:907-915.

Egan, A. R. and Q. R. Rogers. 1978. Amino acid imbalance in ruminant lambs. Aust. J. Agric. Res. 29:1263

Ellis, W. C., J.H. Matis, T.M. Hill and M.R. Murphy. 1994. Methodology for estimating digestion and passage kinetics of forages. Chapter 17. Proceedings of Conference on Forage Quality, Evaluation, and Utilization. Editor: George C. Gahey Jr.. American Society of Agronomy Press, Madison, Wisconsin.

Fraser, D. L., B. K. Hamilton and D. P. Poppi. 1990. Effect of duodenal infusion of protein or amino acids on growth and body composition of lambs consuming fresh herbage. Proc. N. Z. Society of Anim. Prod. 50:43-47.

Fraser, D. L., D. P. Poppi and T. J. Fraser. 1992. The effect of protein or amino acid supplementation on growth and body composition of lambs grazing white clover. Proceedings of the third International Symposium on the Nutrition of Herbivores, p. 22. The Malaysian Society of Animal Production, Selangor, Malaysia.

Hill, T. M. 1991, Effects of source of supplemental nutrients on forage intake, digestive kinetics and protein supply to the small intestine of grazing calves. Ph. D. Dissertation. Texas A&M University, College Station, TX.

Hill, T. M., and W. C. Ellis. 1991. Effect of fish meal or feather meal supplementation on intake, digestion, and weight gains of calves grazing bermudagrass. Beef Cattle Research in Texas. 35-36.

NRC. 1985. Ruminant Nitrogen Usage. National Academy Press. Washington, D. C.

Rouquette, F. M., Jr., M. J. Florence, and W. C. Ellis. 1993. Use of fishmeal and feathermeal rations to supplement steers grazing bermudagrass. Overton Field Day Reports. 95-96.

Russell, J. B., J. D. O' Conner, D. G. Fox, P. J. Van Soest and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. An. Sci. 70:3551.

Russell, J. B., R. Onodera, T. Hino. 1991. Ruminal protein fermentation: New perspectives on previous contradictions. *In* Physiological Aspects of Digestion and Metabolism in Ruminants. Proceed. 7th International Symposium on Ruminant Physiology. p. 681-697.

Yang, C. M and J. B. Russell. 1993. Effect of Monensin on the specific activity of ammonia production by ruminal bacteria and disappearance of nitrogen from the rumen. Appl. Environ. Microbiol. 59:3250-3254.