Prediction of Duodenal Nitrogen Supply from Degradation or Organic and Nitrogenous Matter In Situ

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ABSTRACT

The contribution of different feedstuffs to nitrogen reaching the duodenum was evaluated in situ. Dacron bags containing barley grain, corn grain, wheat silage, corn silage, alfalfa hay, rye grass, whole cottonseeds, or soybean meal were suspended in the rumens of three dairy cows fed roughage and concentrate diets. The effective degradability of the nitrogenous and organic matter of feedstuffs was calculated from their residues after incubation in the rumen for 3, 6, 9, 12, 24, 36, or 48 h. The duodenal nitrogen content at ruminal outflows of 2, 5, or 8%/h was calculated as the sum of undegradable dietary nitrogen and potential microbial nitrogen (assuming 32 g N/kg ruminally degradable organic matter). Comparison of the in situ estimates with previously reported in vivo measurements of duodenal nitrogen in cattle fed diets with similar ingredients to the tested feedstuffs yielded a linear relationship ($r^2 = .887$). The dacron bag technique appears to hold promise for the prediction of nitrogen flow to the duodenum.

INTRODUCTION

Modern systems (1, 17) for the determination of N supply in ruminants are based on estimates of the amount and quality of N reaching the duodenum. The two main components of such estimates are microbial and residual dietary N (17). Degradation of dietary N can be evaluated directly from feedstuffs suspended in dacron bags in the rumen (12). Although such evaluation might be subject to errors arising from chemical, physical, and nutritional effects, it is considered at present the most feasible method for estimation of feedstuff degradability in the rumen (1).

In vivo estimation of flow of microbially synthesized to the duodenum is commonly performed in animals fitted with ruminal and duodenal cannulae and is based on the assessment of digesta flow and the use of microbial markers (3). The accuracy of this method is influenced by the relative proportions of protozoa and bacteria in the rumen and the adequacy of the microbial markers used (7), and requires representative sampling of both the solid and liquid phases (19). As an alternative to the in vivo approach, a method based on assay of the degradable organic matter (OM) in the rumen might facilitate prediction of the microbial N output, since digested OM is a primary determinant of the N entering the small intestine (17).

Hovell et al. (9) proposed that the potential degradability of feedstuffs measured by the dacron bag technique may serve as a basis for estimation of the maximum amount of degradable OM available to microorganisms. However, a method for the evaluation of microbial N based on in situ degradation of OM in the rumen has not yet been described. The objective of the present work was to devise a means of estimating both the degradable OM and the degradable nitrogenous matter in feedstuffs incubated in the bovine rumen. Because degrad-

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Received October 31, 1988.
Accepted March 17, 1989.

TABLE 1. Chemical composition of feeds (percentage DM basis) supplied to the cows in the different diets.

	100% roughage	18% roughage			
Ingredient	Alfalfa hay	Corn silage	Vetch hay	Cotton seeds	Concentrates[1]
Organic matter	90.5	92.6	91.7	94.8	92.4
CP	16.0	10.3	13.0	24.4	16.5
NDF	47.5	43.4	48.0	47.0	12.5
ADF	39.8	30.2	32.0	35.5	5.9
Lignin	8.4	2.5	8.2	10.4	1.6

[1] Ingredients in concentrates (% DM): corn grain, 48; barley grain, 24; soybean meal, 22; mineral and vitamin mix, 6.

ability in situ might be influenced by the basal diet (12), we compared the results from cows fed roughage and concentrate diets.

MATERIALS AND METHODS

Dacron bags were suspended in the rumens of three rumen-cannulated Israeli-Holstein dairy cows, two of them in mid-lactation and one dry, each weighing about 600 kg. Cows were housed in individual stalls with free access to water. Each cow received two successive dietary treatments with an adaptation period of 2 wk. Experimental diets consisted of either (on DM basis) 100% roughage (alfalfa hay) or 18% roughage (9% corn silage and 9% vetch hay) and 82% concentrates (68% grains and 14% whole cottonseeds). Their chemical compositions are given in Table 1. The feed was provided for ad libitum intake. Daily DM intake was 14, 11, and 9 kg with the 100% roughage diet (for the two lactating and the dry cow) and 21, 19, and 11 kg with the 18% roughage diet, respectively.

The chemical composition of the individual feedstuffs used for in situ incubations are listed in Table 2. Rye grass, corn silage, and wheat silage were dried at 60°C for 48 h prior to grinding. All feedstuffs were ground fine enough to pass through a 1.5-mm screen. Dry matter content was determined by drying at 105°C for 24 h. Ash and N (Kjeldahl) were determined in the dry form.

Feed samples were weighed into bags of dacron cloth (Amka, Israel) with a mean pore size of 45 μ (range 35 to 55 μ). Each bag measured 12 cm × 6 cm, providing a large enough internal surface for digestion of 3 g DM. Bags were prepared in duplicate for two of the cows and in triplicate for the third. For incubation in the rumen, the dacron bags were progressively introduced into large net bags connected by a nylon cord to the cap of the ruminal cannula and kept there for 48, 36, 24, 12, 9, 6, and 3 h. The dacron bags were removed from the rumen together and were immediately rinsed with cold tap water in a washing machine. Disappearance at zero incubation

TABLE 2. Chemical composition (percentage DM basis) of feedstuffs incubated in situ in the rumen.

Ingredient	DM	OM[1]	CP	NDF	ADF	L[2]
Barley grain	87.2	97.5	12.9	20.1	7.3	2.1
Corn grain	86.9	98.2	10.5	12.1	3.9	2.0
Wheat silage	96.2	92.6	10.0	51.3	35.4	5.9
Corn silage	91.0	92.6	10.3	43.4	30.2	2.5
Alfalfa hay	88.4	90.5	16.0	47.5	39.8	8.4
Rye grass	88.1	87.2	24.4	37.7	24.8	2.6
Whole cottonseeds	92.1	94.8	24.4	47.0	35.5	10.4
Soybean meal	88.3	92.8	50.5	14.1	9.3	1.3

[1] OM = Organic matter.

[2] L = Lignin.

time was evaluated in bags immersed in water at 39°C for 1 h. Percentage of residual organic and nitrogenous matter were determined after drying the bags overnight at 105°C.

The disappearance of organic and nitrogenous matter from the rumen, as well as their effective degradation (i.e., rumen degradability of organic and nitrogenous matter corrected for outflow rate from the rumen), were determined as proposed by (18). Data were fitted to the exponential: $P = a + b(1 - e^{-ct})$, where P = degradation after t hours, and a, b, and c were calculated for each feed by an iterative, minimal least square program using the Marquard procedure. The effective degradability (d) of OM and nitrogenous matter in the rumen was calculated using these three constants and the estimated rate of particulate outflow from the rumen (k): $d = a + [(b \cdot c)/(c + k)]$. Chosen values of k were 2, 5, and 8%/h, which may be representative of low, medium, and high feeding amounts (1). The amount of microbially synthesized N was estimated from the effective degradability of OM and by assuming an efficiency of 32 g N/kg OM digested in the rumen (1).

Data were subjected to analysis of variance. Cows were treated as random blocks and the significance of dietary treatments was tested against cows × feedstuffs. When F values were significant ($P<.05$), dietary treatments were compared at probabilities of .05. Data are reported as means with standard error of the mean.

RESULTS

Coefficients of determination (r^2) were increased when data on the disappearance of feedstuffs from bags immersed in water were included in the regression set at zero incubation time. The coefficients of determination for the disappearance curves of feedstuffs incubated in the rumen were above .89 ($n = 8$, $P<.001$) in all cases except one, where r^2 was .81 ($P<.01$) for the disappearance of OM of whole cottonseed from one cow fed a roughage diet.

The constants from fitted exponential a, b, and c for N degradability differed considerably among test feedstuffs. However, the constants for each feedstuff did not vary according to diet (Table 3). The effective N degradability of each feedstuff was strongly affected by the rate of particulate outflow from the rumen. Thus, regardless of the diet, an increase in ruminal outflow from 2 to 8%/h was associated with a decrease in the effective N degradability of about 10% in wheat silage, corn silage, and whole cottonseeds; about 20% in barley grains, alfalfa hay, and rye grass; and about 40% in corn grains and soybean meal. At each outflow rate the effective N degradability varied among feedstuffs and was moderately but significantly affected by the type of diet. The mean effective N degradability at all three rates of ruminal outflow was 5% higher ($P<.05$) for the roughage than for the concentrate diet. The mean proportions of residual dietary N in the rumen (i.e., total dietary N minus effective degradable N) for all feedstuffs, calculated as an overall average for the two diets, were 20% ± 2, 30% ± 6, and 36% ± 9) for ruminal outflow rates of 2, 5, and 8%/h, respectively.

Also in the case of OM degradability, the fitted exponential constants a, b, and c differed significantly between test feedstuffs. Although the type of diet showed only a tendency to affect constant a ($P = .058$), its effects on b and c were significant (Table 4). The mean values were, respectively, 3.5 and 13.9% higher for a and b and 31.1% lower for c in the roughage diet than in the concentrate diet. The mean effective degradability of feedstuff OM at ruminal outflow rates of 2, 5, and 8%/h were 11.0, 9.9, and 8.6% higher ($P<.05$), respectively, for the roughage diet than for the concentrate diet. The mean values of ruminal OM degradability calculated as an average of all feedstuffs in the two diets, were 61% ± 4, 53% ± 4, and 48% ± 3 for ruminal outflow rates of 2, 5, and 8%/h, respectively.

DISCUSSION

The higher effective ruminal degradability of both N and OM of feedstuffs for the roughage diet than for concentrate diet (Table 3 and 4) was presumably a function of microbial species or microbial enzyme activities with the two diets (12). The effective degradability values of N estimated in situ in the present study were similar to reported values in vivo and in situ degradability for the same feedstuffs (4, 15, 25). This correspondence supports the finding (15) that in dairy cows the effective degradability of N in situ is comparable to its degradability in vivo.

Because the quantity of degraded OM in the rumen largely determines the amounts of pro-

TABLE 3. Fitted exponential constants for of nitrogen degradability and the effective degradability of nitrogen.

Feedstuff and diet	a[1]	b	c	Degradability[2] P2	P5	P8
	(g/kg DM)	(g/kg DM)	(h^{-1})	(g/kg DM)	(g/kg DM)	(g/kg DM)
Barley grain						
R[3]	4.1	15.4	.173	17.7	15.8	14.3
C[4]	4.1	15.1	.173	17.5	15.6	14.2
Corn grain						
R	3.5	16.0	.035	13.3	9.8	8.2
C	3.4	16.0	.040	13.4	10.0	8.4
Wheat silage						
R	8.4	4.5	.228*	12.3	11.8	11.4
C	8.4	4.2	.460	12.1	11.6	11.3
Corn silage						
R	9.5	4.4	.132	13.0	12.3	11.9
C	9.4	4.2	.188	12.5	11.9	11.6
Alfalfa hay						
R	8.4	14.1	.130	20.5	18.4	17.0*
C	8.1	15.7	.061	19.6	16.4	14.6
Rye grass						
R	16.1	23.3	.104	35.7	31.9	29.3
C	16.6	20.4	.101	33.5	30.2	27.8
Whole cottonseeds						
R	8.3	25.3	.501	32.6	31.2	29.9
C	8.3	24.9	.439	32.1	30.5	29.3
Soybean meal						
R	6.7	78.3	.056	64.3*	48.0*	38.9*
C	7.1	73.2	.055	59.6	44.3	35.9
SE	.2	.1	.067	1.0	.8	.6
Significance (*P* values)						
Feedstuffs (F)	.001	.001	.001	.001	.001	.001
Diet (D)	.558	.365	.557	.028	.014	.021
F × D	.616	.831	.460	.289	.274	.386

[1] a,b,c = Fitted exponential constants for nitrogen degradability.

[2] Effective degradability of nitrogen at ruminal outflow rates of 2, 5, and 8%/h.

[3] Roughage.

[4] Concentrate.

*Differencce ($P<.05$) between diets.

tein synthesized microbially, an increase in ruminal outflow may have two opposite effects on the amount of N reaching the duodenum, i.e., an increase in residual dietary N may be accompanied by a decrease in microbial N.

Wide variation has been reported in the efficiency of microbial protein synthesis in the rumen, ranging from 10 to 70 g N/kg degraded OM (3). This variation might be attributable to differences in fermentation pattern and N source. Under standard conditions there is presumably less variation. A mean microbial efficiency factor of 32 g N/kg OM degraded in the rumen has been proposed (1) and was adopted for calculations in this work.

The aim of the present study was to determine whether the in situ degradation of nitrogenous and OM in the rumen can serve as a basis for the prediction of N reaching the duodenum. For each feedstuff, the amount of N in the duodenum was calculated by assuming that residual dietary N is equal to the difference between the N content of the ingested feedstuff and its effective degradability in the rumen.

TABLE 4. Fitted exponential constants for organic matter degradability and the effective degradability of organic matter.

Feedstuff and diet	a[1]	b	c	Degradability[2] P2	P5	P8
	(g/kg DM)		(h^{-1})	(g/kg DM)		
Barley grain						
R[3]	125	725	.309	806	749	701
C[4]	130	686	.331	772	717	671
Corn grain						
R	111	813	.066	734	573	478
C	122	791	.062	711	551	459
Wheat silage						
R	237*	386*	.078*	539*	467*	423*
C	201	271	.394	445	418	399
Corn silage						
R	213*	467	.083	589*	504*	451
C	190	349	.177	496	450	418
Alfalfa hay						
R	151	444	.125	532*	466*	419*
C	143	413	.084	472	397	350
Rye grass						
R	273	584*	.068	724*	609*	541*
C	291	447	.065	629	539	487
Whole cottonseeds						
R	199	387	.181	539*	489*	452*
C	181	312	.252	468	437	412
Soybean meal						
R	219	724	.065	772*	628*	543*
C	216	709	.054	629	539	487
SE	7	27	.049	14	12	12
Significance (*P* values)						
Feedstuffs (F)	.001	.001	.001	.001	.001	.001
Diet (D)	.058	.001	.035	.001	.001	.001
F × D	.005	.164	.026	.091	.508	.502

[1] a,b,c = Fitted exponential constants for organic matter degradability.

[2] Effective degradability of organic matter at ruminal outflow rates of 2, 5, and 8%/h.

[3] Roughage.

[4] Concentrate.

*Difference ($P<.05$) between diets.

Assuming an efficiency of 32 g N/kg ruminally digested OM (1), the potential microbial N was calculated as .032 times the effective degradable OM in the rumen. For the two diets, the calculated amounts of N from the different feedstuffs reaching the duodenum at different rates of ruminal outflow are shown in Table 5.

The type of diet had only a minor effect on the amount of N from each feedstuff reaching the duodenum with no diet-associated differences at ruminal outflow rates of 5 or 8%/h. The amount of N reaching the duodenum was unaffected by the rates of ruminal outflow in the case of barley grains, alfalfa hay, rye grass, and whole cottonseeds. An increase in ruminal outflow rate was accompanied by a decrease in the amount of duodenal N from corn silage, wheat silage, and corn grains but by an increase in duodenal N from soybean meal. These differences in response to different ruminal outflow rates may be a reflection of differences in the degradability of nitrogenous and OM in these feeds.

For feedstuffs containing a moderate amount of dietary N (1.5 to 2%), the amount of N reaching the duodenum (Table 5) was higher

TABLE 5. Amounts of nitrogen reaching the duodenum (g/kg DM), as predicted by in situ measurements.

Feedstuff and diet	Ruminal outflow		
	2%/h	5%/h	8%/h
Barley grain			
R[1]	28.7	28.8	28.7
C[2]	27.8	28.0	27.9
Corn grain			
R	27.0	25.4	24.0
C	26.2	24.4	23.2
Wheat silage			
R	20.9*	19.1	18.1
C	18.2	17.7	17.4
Corn silage			
R	22.3*	20.3	19.0
C	19.9	19.0	18.3
Alfalfa hay			
R	22.1	22.1	22.0
C	21.1	21.9	22.2
Rye grass			
R	26.5	26.7	27.1
C	25.6	26.2	26.8
Whole cottonseeds			
R	23.7	23.5	23.6
C	21.9	22.4	22.9
Soybean meal			
R	41.2*	52.9*	59.3
C	44.3	54.9	60.7
SE	.8	.6	.6
Significant (*P* values)			
Feedstuffs (F)	.001	.001	.001
Diet (D)	.030	.102	.291
F × D	.043	.194	.584

[1] Roughage.

[2] Concentrate.

*Difference ($P<.05$) between diets.

than the dietary N content, probably as a result of utilization of recycled N. The potential of duodenal N exceeded dietary N by 13% in wheat silage, 17% in corn silage, 38% in barley grain, and 44% in corn grains. However, in feedstuffs with relatively high dietary N, the potential of N reaching the duodenum was lower than the dietary N content, presumably reflecting a deficiency of degradable energy relative to the N content of these feeds. Thus, the amounts of duodenal N were 14% lower than dietary N in alfalfa hay, 30% lower in soybean meal, 32% lower in rye grass, and 40% lower in whole cottonseeds. This pattern of contribution of feedstuffs to animal's overall supply of N is analogous to that described for the potential of urea fermentation (2). In our study, however, the use of dacron bags for convenient in situ measurement of degradable OM and nitrogenous matter in the rumen and its extrapolation to duodenal N made it unnecessary to resort to microbial and flow markers and duodenal cannulas.

The values of duodenal N shown in Table 5 were calculated for each feedstuff separately. These values represent the potential amount of N only when N and energy are not limiting. This would occur only if the animal receives a balanced diet in which the different feed ingredients complement one another. In the present work, the contribution of each feedstuff to duodenal N was tested in isolation and not as a component of integrated diet. However, we compared our predictions with published results obtained with diets containing ingredients similar to our tested feedstuffs (Table 6).

Each predicted in situ value in Table 6 is expressed as the overall mean of values for feedstuffs under both dietary treatments at ruminal outflow rates of 5 and 8%/h. The results (in g N/kg DM) were multiplied by the corresponding in vivo daily DM intake and compared with in vivo determinations ($n = 22$) of duodenal N in cattle. Some of the in vivo studies made marginal use of additional feedstuffs whose contribution to duodenal N was evaluated with the following assumptions. For roughage feedstuffs, intestinal N was assumed to be equal to the dietary N content. For energy feedstuffs, the nitrogenous value of barley grains (i.e., 28.4 g N/kg DM, Table 5) was used. The mean contribution of these additional feedstuffs to the duodenal N in such cases was 3.3% ± 1.3.

Our in situ evaluations were linearly correlated ($r^2 = .887$, $P<.001$) with the in vivo values. This value of r^2 is higher than that describing the correlation between N intake and duodenal N content measured in vivo in the studies listed in Table 6 ($r^2 = .804$). The standard deviation of the mean difference between in vivo and in situ evaluations was 12% with the largest deviations observed in dairy cows with a daily duodenal N flow of 320 to 490 g. These differences can probably be related in part to differences in the chemical composition of feeds used in the in vivo and in situ trials. An additional source of error is the predicted

TABLE 6. Comparison between in vivo and in situ estimates of duodenal nitrogen.

Diet	Reference	In vivo	In situ[1]	Difference
		—— (g	N/d) ——	(%)
1	(14)	37	40	+8
2	(26)	69	67	−3
3	(29)	81	78	−4
4	(10)	158	149	−6
5	(6)	165	167	+2
6	(5)	173	148	−14
7	(8)	198	213	+8
8	(8)	208	207	−1
9	(21)	248	276	+11
10	(10)	295	299	+1
11	(16)	324	388	+20
12	(23)	331	317	−4
13	(13)	342	337	−1
14	(30)	365	436	+19
15	(23)	372	399	+7
16	(22)	376	442	+18
17	(23)	382	450	+18
18	(11)	389	463	+19
19	(23)	421	448	+6
20	(27)	451	356	−21
21	(24)	462	402	−13
22	(28)	491	405	−18
Mean				+2
SD				12

[1] Obtained by multiplying mean duodenal nitrogen values at ruminal outflow rates of 5 and 8%/h (Table 5) by the corresponding in vivo dry matter intake.

microbial N value. The mean estimate of microbial efficiency obtained from the in vivo studies cited in Table 6 was 31 g N/kg OM degraded in the rumen (SE = 3). It should be emphasized that the accuracy of current methods for the evaluation of microbial synthesis in the rumen is limited (20). The microbial contribution to duodenal N calculated by the present in situ method, i.e., 32 to 80% for the different feedstuffs is in good agreement with the assessment of (20) that 40 to 80% of the duodenal protein flow is derived from microbial synthesis.

A recent survey of scientists working on ruminant nutrition (19) revealed that 67% are currently using the dacron bag technique, but only 2% expect it will continue to be of use in the future. Future validation of in situ predictions of duodenal N might lead to more widespread adoption of this technique. In particular, the good correlation between the in vivo measurement and our predicted values suggests the potential usefulness of the dacron bag technique for in situ-based prediction of N reaching the duodenum.

REFERENCES

1 Agricultural Research Council. 1984. The nutrient requirements of ruminant livestock. Suppl. No 1. Commonw. Agric. Bur. Farnham Royal, Slough, Engl.

2 Burroughs, W., D. K. Nelson, and D. R. Mertens. 1975. Protein physiology and its application in the lactating cow: the metabolizable protein feeding standard. J. Anim. Sci. 41:933.

3 Demeyer, D., and C. Van Nevel. 1986. Influence of substrate and microbial interaction on efficiency of rumen microbial growth Reprod. Nutr. Dev. 26:161.

4 Erdman, R. A., J. H. Vandersall, E. Russek-Cohen, and G. Switalski. 1987. Simultaneous measures of rates of ruminal digestion and passage of feeds for prediction of ruminal nitrogen and dry matter digestion in lactating dairy cows. J. Anim. Sci. 64:565.

5 Garrett, J. E., R. D. Goodrich, J. C. Meiske, and M. D. Stern. 1987. Influence of supplemental nitrogen, dry matter and organic matter and on in vivo rate of ruminal protein degradation. J. Anim. Sci. 64:1801.

6 Goetsch, A. L., and F. N. Owens. 1985. Effect of level and diurnal variation of dietary concentrate on digestion and passage rate in beef steers. Livest. Prod. Sci. 13:267.

7 Harrison, D. G., and A. B. MacAllan. 1980. Factors affecting microbial growth yields in the reticulo-rumen. Page 205 *in* Digestive physiology and metabolism in ruminants. Y. Ruckenbusch and P. Thivend, ed. MTP Press, Lancaster, PA.

8 Horner, J. L., C. E. Coppock, J. R. Moya, J. M. Labore, and J. K. Lanham. 1988. Effect of niacin and whole cottonseed on ruminal fermentation, protein degradability, and nutrient digestibility. J. Dairy Sci. 71:1239.

9 Hovell, F. D. DeB, J.W.W. Ngammbi, W. P. Barber, and D. J. Kyle. 1986. The voluntary intake of hay by sheep in relation to its degradability in the rumen as measured in nylon bags. Anim. Prod. 42:111.

10 Hvelplund, T., and J. Madsen. 1985. Amino acid passage to the small intestine in dairy cows compared with estimates of microbial protein and undegraded dietary protein from analysis on the feed. Acta Agric. Scand. Suppl. 25:21.

11 Kung Jr, L., J. T. Huber, and L. D. Satter. 1983. Influence of nonprotein nitrogen and protein of low rumen degradability on nitrogen flow and utilization in lactating dairy cows. J. Dairy Sci. 66:1863.

12 Lindberg, J. E. 1985. Estimation of rumen degradability of feed proteins with the in sacco technique and various in vitro methods: a review. Acta Agric. Scand. Suppl. 25: 64.

13 Lu, C. D., N. A. Jorgensen, and L. D. Satter. 1988. Site and extent of nutrient digestion in lactating dairy cows fed alfalfa protein concentrate or soybean meal. J. Dairy Sci. 71:697.

14 McAllan, A. B., and R. H. Smith. 1984. The efficiency of microbial protein synthesis in the rumen and the degradability of feed nitrogen between the mouth and the abomasum of steers given different diets. Br. J. Nutr. 51: 77.

15 Madsen, J., and T. Hvelplund. 1985. Protein degradation in the rumen, a comparison between in vivo, nylon bag,

in vitro and buffer measurements. Acta Agric. Scand. Suppl. 25:103.

16 Merchen, N. R., and L. D. Satter. 1983. Changes in nitrogenous compounds and sites of digestion of alfalfa harvested at different moisture contents. J. Dairy Sci. 66: 789.

17 National Research Council. 1985. Ruminant nitrogen usage. Subcommittee on nitrogen usage in ruminants. Natl. Acad. Sci., Washington, DC.

18 Orskov, E. R., and I. McDonald. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. 92:499.

19 Owens, F. N. 1987. New techniques for studying digestion and absorption of nutrients by ruminants. Fed. Proc. 46:283.

20 Owens, F. N., and W. G. Bergen. 1983. Nitrogen metabolism of ruminant animals: historical perspective, current understandings and future implications. J. Anim. Sci. 57(Suppl. 2):498.

21 Pena, F., H. Tagari, and L. D. Satter. 1986. The effect of heat treatment of whole cottonseed on site and extent of protein digestion in dairy cows. J. Anim. Sci. 62:1423.

22 Price, S. G., L. D. Satter, and N. A. Jorgensen. 1988. Dehydrated alfalfa in dairy cow diets. J. Dairy Sci. 71: 727.

23 Rode, L. M., D. C. Weakley, and L. D. Satter. 1985. Effect of forage amount and particle size in diets of lactating dairy cows on site of digestion and microbial protein synthesis. Can. J. Anim. Sci. 65:101.

24 Santos, K. A., M. D. Stern, and L. D. Satter. 1982. Protein degradation in the rumen and amino acid absorption in the small intestine of lactating dairy cattle fed various protein sources. J. Anim. Sci. 58:244.

25 Satter, L. D. 1986. Protein supply from undegraded dietary protein. J. Dairy Sci. 69:2734.

26 Smith, R. H., A. B. McAllan, D.D Hewitt, and P. E. Lewis. 1978. Estimation of amounts of microbial and dietary nitrogen compounds entering the duodenum of cattle. J. Agric. Sci. 90:557.

27 Stern, M. D., L. M. Rode, R. W. Prange, R. H. Stauffacher, and L. D. Satter. 1983. Ruminal protein degradation of corn gluten meal in lactating dairy cattle fitted with duodenal T-type cannulae. J. Anim. Sci. 56: 194.

28 Stern, M. D., K. A. Santos, and L. D. Satter. 1985. Protein degradation in rumen and amino acid absorption in small intestine of lactating dairy cattle fed heat-treated whole soybeans. J. Dairy Sci. 68:45.

29 Wanderley, R. C., C. B. Theurer, and M. Poore. 1987. Duodenal bacterial and nonbacterial protein supply in steers fed forage and grain diets. J. Anim. Sci. 64:295.

30 Zerbini, E., C. E. Polan, and J. H. Herbein. 1988. Effect of dietary soybean meal and fish meal on protein digesta flow in Holstein cows during early and midlactation. J. Dairy Sci. 71:1248.