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Discontinuous roughage delivery on digestion, rumen metabolism, feed efficiency and liveweight gain of beef steers fed a concentrate diet

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Abstract

Two experiments were carried out to study the effect of feeding a total mixed ration (TMR) compared to feeding the roughage portion of the diet once every two days and separated of the daily delivered concentrate mixture on dry matter intake, nutrient digestibility, ruminal metabolism, feed efficiency and liveweight gain. In Trial 1, thirty beef steers (Braford and Braford × Criollo; initial BW = 259 ± 27 kg) were used in a 69-d feeding trial. Treatments were: total mixed ration (TMR), and the same proportion of ingredients for the ration but roughage offered once every 2-d and separated of the daily delivered concentrate portion of the diet (REOD). Treatments were arranged in a completely randomized design (three pens/ treatment). In both treatments, daily offered ration had on dry matter basis 90% concentrate and 10% grass hay (*Setaria italica*). Average daily gain (ADG) did not differ among treatment (1013 vs. 1080 g/d for TMR vs. REOD respectively; SEM = 95 g/d). Dry matter intake was greater in TMR compared to REOD ($P < 0.01$). Gain to feed ratio tended to be better for REOD than TMR ($P = 0.07$). In Trial 2, four rumen cannulated steers (Braford) were used in an experiment with a crossover design. Treatments were arranged as a 2 × 2 factorial design, where the first factor consisted of roughage level (RL): D1) 14% roughage: 86% concentrate and D2) 7% roughage: 93% concentrate. The second factor was roughage delivery system (RDS; as it was described for Trial 1): TMR and REOD. There were not RL × RDS interactions for intake and digestion (OM, CP, NDF, and starch). Both RL were similar for intake and digestion. Roughage delivery system did not significantly affect intake and digestion of OM, CP, NDF, and starch measured by total fecal collection. Total organic acids (TOA), acetate to propionate ratio (A:P), pH, and rumen ammonia concentrations were not affected by RL and RDS. In conclusion, under the conditions of these trials, steers fed a separated roughage source once every 2-d had similar ADG, and tended to be more efficient

with regard to TMR. Total tract digestibility and rumen environment traits (pH, VFA, and ammonia) were not affected in response to discontinuous roughage delivery in comparison to TMR ration.

Keywords: average daily gain, digestibility, ruminal fermentation, forage supply.

Introduction

Total mixed rations (TMR) are the most common feed delivery system in feedlot operations. Small proportions of roughage in high concentrate diets (i.e., 5 to 25% DM basis) improve dry matter intake (DMI), average daily gain (ADG), and feed efficiency (Galyean and Defoor, 2003; Pritchard and Bruns, 2003). When forage is eliminated from concentrate diets, intakes and daily gain decrease, meanwhile the occurrence of ruminal dysfunction and acidosis increase. Roughage fiber in concentrate diets has a physic-chemical function of stimulating chewing and saliva flow increasing energy intake and reducing ruminal dysfunction (Defoor et al 2002; Galyean and Defoor, 2003; Krehbiel et al 2006). However, the cost of processing the roughage is often equal to the cost of the roughage itself. Additionally, labor costs as well as dust from processing are also increased when feeding roughage in a TMR. In general middle- and small-scale feeding operations cannot afford processing and mixing equipments. The principle of a TMR is based in a concept of nutrition on an "animal average" basis. However, at least as many as half of the animals within a group differ from mean nutrient requirements and tolerances (Villalba and Provenza, 1996; Scott and Provenza, 1999). Forbes (2003) proposed that animals select ingredients in response to permanent changes in their individual demands throughout cycles of learning and integration that adjust daily. Some studies with dairy cow herds (Holter et al 1977; Nocek et al 1986) compared roughage delivery separated from concentrate vs. TMR, but not in a discontinuous roughage delivery way. Those authors did not observe difference in feed intake and animal performance. Despite the fact that the animal cannot regulate composition of the ration offered, there are also differences in rate of passage between concentrates and roughages throughout the gastrointestinal tract (Moore et al 1990; Poore et al; 1990). Differential passage rate between roughage and concentrate might also allow to maintain an adequate level of fiber in the rumen even when roughage is fed separated and in a discontinuous way. Thus, it was hypothesized that discontinuous roughage delivery and separated of the concentrate portion of the diet should allow beef steers to adjust their individual concentrate to roughage ratio of the diet. Consequently, steers fed discontinuous and separated forage should have similar performance than those fed a TMR. In this regard, to our knowledge, there is no information about discontinuous roughage delivery in beef cattle fed a concentrate diet. The objective of this study was to evaluate dry matter intake, total tract digestibility, rumen fermentation, feed efficiency and daily weight gain in beef steers fed either a total mixed ration or the roughage portion of the diet separated of concentrate and alternated among days.

Materials and Methods

Description of studies

Trial I. This study was conducted at the Experimental Station of Santiago del Estero Instituto Nacional de Tecnología Agropecuaria "La María". Thirty beef steers (Braford and Braford × Criollo; initial BW = 259 ± 27 kg) were used in a 69-d finishing study. Seers were allotted, by breeds and initial BW, in three pens per treatment (5 steers/ pen). Treatments were: a total mixed ration (concentrates and roughage all mixed; TMR) and the same proportion of ingredients but the roughage offered once every 2-d and separated of the daily fed concentrate portion of the diet (roughage every other day, REOD). Roughage in REOD was fed on the first day of a two days sequence of feeding. At the beginning of the trial steers were treated against internal and external parasites and injected with vitamins A, D, and E (Ivermectin 3.15%; Vetanco S.A., Vicente López, Buenos Aires, Argentina), and a mineral-vitamin complex (Iodine-Calcium and B_{12}; Chinfield S.A.; Buenos Aires, Argentina). Diet in both treatments was formulated following the recommendations of NRC (1996) for beef cattle. A 15-d period was allowed for adaptation to the finishing diet, in which the ration started containing 55% hay (*Setaria italica*; Foxtail bristlegrass; chopped through a 40 mm × 40 mm screen for TMR and unchopped for REOD) to gradually increase grain content of the diet up to 81%. Ingredient and nutrient composition of fed diet are reported in Table 1. Steers were fed *ad libitum* once a day at 9:00 h. In REOD the amount of hay delivered once every 2-d was twice the hay daily fed in TMR. In both treatments each component of the ration was offered *ad libitum*. Daily refusals were weighted, recorded, and discarded after sampling. Daily ration and refusal samples were composited across days for dry matter (DM), laboratory analysis and determination of ingested fraction of the diet. Measures of efficiency were calculated by determination of ADG for each animal, and then by group. Concentrate and roughage DM intake as well as feed efficiency were determined by group of animals within a pen. Both initial and final BW of steers were measured after a 48-h fasting period during two consecutive days, with only access to water. Group DM intake and ADG was used to calculate feed efficiency. Intra-pen ADG variability (ADGipv) was calculated as the standard deviation in ADG within the pen.

Table 1. Composition of the diet (Trial I).

Ingredients	DM basis (%)
Ground corn	81.0
Whole cottonseed	7.0
Grass hay[1]	10.0
Urea	0.65
Limestone	1.00
Mineral Mix[2]	0.35
Nutrient composition	
DM	87.8
OM	-
CP	13.5
Diet NDF	26.8
Forage NDF	7.2
Diet ADF	13.6
Forage ADF	4.43

[1] Foxtail bristlegrass (*Setaria italica*).

[2] Mineral mix: Copper sulfate 2.20%, Calcium Iodate 0.06%, Cobalt carbonate, 0.021%; Magnesium Oxide 10%, Zinc sulfate 10.8%, Sodium selenite 0.021%, Iron sulfate 5.82%, Calcium carbonate 4%, Monensin 10%.

Trial II. Four rumen cannulated beef steers (Braford; initial BW = 266 ± 18 kg) were used in a crossover experiment with 4 treatments. Composition of the diet fed (dry matter basis) is reported in Table 2. Each steer received intramuscular injections against internal and external parasites, vitamins A, D, and E (Ivermectin 3.15%; Vetanco S.A., Vicente López, Buenos Aires, Argentina), and a mineral-vitamin complex (Iodine-Calcium and vitamin B_{12}; Chinfield S.A., Buenos Aires, Argentina) at the beginning of the study. Steers were housed in individual stalls (1.5 × 2.5 m) with continuous access to fresh water. Steers were fed once daily at 130% based on average intake of the previous 3 days. Roughage source of the diets was chopped hay (*Setaria italica*; Foxtail bristlegrass; chopped through a 40 mm × 40 mm screen). Treatments consisted of roughage delivery system (such as it was described for Trial 1; RDS): TMR and REOD. In REOD forage was fed the first day of feeding during two consecutive days. Each 24-d period included 14 d for treatment adaptation, a 7 d interval for monitoring forage intake and total fecal output (feces were collected during the last 6 d), a 1 d rest interval, and a 2 d interval for monitoring ruminal fermentation. Digestibility was determined by total fecal collection using forage samples collected on d 14 to 19, diet refusal samples collected on d 15 to 20, and fecal samples collected on d 16 to 21 for each period (Cochran and Galyean, 1994). Fecal bags were changed and weighed once daily at 0800 h. Samples of rumen liquor were collected on d 22 and d 23, obtained with the aid of a suction strainer (Raun and Burroughs, 1962; 19 mm diameter, 1.5 mm mesh). In order to compare the effect of discontinuous feeding of roughage, on d 22 and 23 samples were collected at 0 (i.e., just before feeding), 2, 4, 8, 12, 24, 28, 32, and 36 h after feeding roughage in REOD for ruminal pH. Ruminal fluid pH was determined using a portable pH meter with a combination electrode (Orion Research, Boston, MA, USA) immediately following each collection. Additionally, ruminal fluid samples were collected at 0, 4, 12, 24, 28, and 36 h after feeding forage source in REOD for total organic acids (TOA = volatile acids [VFA] plus lactate) and ammonia analysis.

Laboratory analysis

Table 2. Composition of the diet (Trial II).

	Diets	
	14.5% Hay	**7.3% Hay**
Ingredients	% of DM basis	
Ground corn	75.3	82.6
Whole cottonseed	8.4	8.3
Grass hay[1]	14.5	7.3
Urea	0.55	0.55
Limestone	0.90	0.90
Mineral Mix[2]	0.35	0.35
Nutrient composition		
DM	88.2	88.0
OM	94.9	95.6
CP	11.6	11.7
Diet NDF	33.1	29.1
Forage NDF	11.3	5.7
Diet ADF	11.3	8.4
Forage ADF	6.2	3.1
Starch	45.3	49.2

[1] Foxtail bristlegrass (*Setaria italica*).

[2] Mineral mix: Copper sulfate 2.20%, Calcium Iodate 0.06%, Cobalt carbonate, 0.021%; Magnesium Oxide 10%, Zinc sulfate 10.8%, Sodium selenite 0.021%, Iron sulfate 5.82%, Calcium carbonate 4%, Monensin 10%.

For Trial I and II components of the diet, refusals, and fecal samples were partially dried in a forced air oven (96 h; 55ºC), weighed, and ground (No. 4 Willey Mill, Thomas Scientific, Swedesboro, NJ; USA) to pass through a 1 mm screen. Ground feeds and refusal samples collected in Trial I, were composited on an equal weight basis among days of feeding. Once dried, ground feeds collected in Trial II were composited among days within period. Refusals and fecal samples collected were composited among days within steer and period in proportion to daily refusals and fecal production. Partially dried samples of feed, refusals, and feces were dried for 24 h at 105º C for DM determination for Trial I and II. Dried samples from Trial II were then ashed for 8 h at 450º C. Feed, refusals, and fecal samples were analyzed for NDF and ADF with the ANKOM-Fiber Analyzer 200 (ANKOM Technology, Fairport, NY, USA) using the procedure described by Komarek (1993). Sodium sulfite was used in the NDF analysis. Heat-stable amylase was used during sample reflux and filtering to ensure complete starch solubilization. The NDF and ADF values reported contain residual ash. Feed samples were analyzed for total N using the procedure of Kjeldahl described by AOAC (1980). Starch determination in feedstuffs and feces was analyzed following the procedure described by Galyean (1997).

In Trial II, ruminal ammonia concentration was determined using the colorimetric procedure of Broderick and Kang (1980). Ruminal VFA were measured using a gas chromatograph (Konik HRGC-3000C) equipped with a Zebron ZB-FFAP Capillary GC Column (30 m x i.d. 0.32, 0.25 µm film thickness; Phenomenex). Oven temperature was programmed at 100°C, hold for 3 min, and increasing at 8 °C/ min from 100 to 230°C. Carrier gas was N_2 at 1.1 mL/min. Split ratio was 30:1. Data were processed with Konikrom-Data System software. Ruminal fluid lactate concentration was measured using the procedure described by Barker and Summerson (1941).

Statistical analysis

In Trial I, intake (DM, components and nutrients), ADG, ADGipv, as well as feed efficiency data were analyzed using a linear model. The experimental unit consisted of each pen. For Trial II a mixed model was used to test intake, digestibility, and rumen fermentation data. Data collected over time for rumen pH, ammonia concentration, and TOA were analyzed as repeated measures.

Results

Trial I

Liveweight gain

Initial and final liveweight did not statistically differ between treatments. Average daily gain and ADG intra-pen variability (ADGipv) did not differ between TMR and REOD (Table 3).

Table 3. Effect of roughage delivey system on animal performance, dry matter intake, and composition (ingredients and nutrients) of ingested diet by beef steers fed a concentrate diet

	Treatments[a]			
	REOD	**TMR**	**SEM[b]**	**P-Value**
Body weight, kg				
Initial	255	263	27	0.73
Final	324	338	26	0.57
DM intake, kg/ head/ d	6.77	8.53	0.27	0.01
ADG, g/d	1013	1080	95	0.43
ADG intra-pen variability, g/d	133	113	53	0.67
Feed efficiency, kg /kg[c]	0,15	0,13	0.01	0.07
Diet composition, % DM				
Concentrate	87.0	85.5	0.2	< 0.01
Grass Hay	13.0	14.5	0.2	< 0.01
Nutrient concentration, %				
NDF	31.7	31.2	0.13	< 0.01
ADF	17.4	19.0	0.10	< 0.01
CP	14.2	14.6	0.02	< 0.01

[a] REOD = roughage every other day; TMR = total mixed ration.
[b] SEM = standard error mean.
[c] kg of liveweight gain per kg dry matter intake.

Dry matter intake.

Total DM intake (TDMI), as well as concentrate and hay in TMR was significantly greater than REOD ($P < 0.01$; Table 3). In agreement with this response, mean intake of fiber (NDF and ADF) was considerably greater in TMR than in REOD ($P < 0.01$; data not shown).

Feed efficiency

The groups of steers fed REOD tended to be more efficient than steers fed TMR ($P = 0.07$). On average gain to feed ratio was 0.15 vs. 0.13 (SEM = 0.01) kg BW gain/ kg DM for REOD vs TMR respectively (Table 3).

Ingredients and nutrient composition of ingested diet

Concentrate proportion of ingested diet, on average all across the study, was greater in REOD than TMR ($P < 0.01$; Table 3), and hay proportion of diet intake was significantly higher in

TMR ($P < 0.01$) than REOD. Neutral detergent fiber concentration of the diet was lower ($P < 0.01$) in TMR than REOD, whereas the ration ingested by TMR groups had significantly more ADF and CP than REOD ($P < 0.01$).

Trial II

No interaction RL × RDS was statistically significant for all variables tested. Thus, it is reported separately main factors response: RDS and RL.

Intake and total tract digestibility

Forage delivery system did not significantly affect OM, NDF, CP, and starch intake (Table 4). Total tract digestibility for OM, NDF, CP, and starch was similar for REOD vs. TMR. Averaged across treatments, OM, NDF, CP, and starch digestibility were 653, 458, 576, and 878 g/kg of DM respectively.

Ruminal fermentation

In this trial rumen pH at any sampling time was relatively high with regard to those values that can lead to ruminal dysfunction. Roughage delivery system did not have any effect on rumen pH (Table 5). On average, rumen pH values were 6.26 and 6.25 for REOD and TMR respectively. However, sampling time did have an effect on rumen pH (Figure 1). Rumen pH increased for the first two hours after feeding to achieve the maximum value, and then decreased to reach the nadir 12 h post feeding for both treatments.

Collection time and RDS did not have an effect on rumen ammonia concentration (Table 5). On average rumen ammonia concentration values were 6.02 and 6.44 mM for REOD and TMR respectively.

Total organic acid concentration in rumen fluid was similar for any treatment combinations and collection time. Treatments as well as collection time did not have an effect in the proportion of main VFA and lactate. There were no effect of RL or RDS on molar proportions of acetate, propionate, butyrate, isobutyrate, valerate, and lactate (Table 5). However, molar proportion of propionate was numerically greater in REOD than in TMR.

Acetate to propionate ratio was not affected by any interaction as well as main effect of RDS, and collection. However, on average TMR had numerically higher acetate to propionate ratio than REOD (2.49 vs. 2.87 for REOD and TMR respectively).

Discussion

Under the conditions of this study, it was observed that discontinuous roughage delivery in a high concentrate diet did not have any negative effect on animal performance (i.e., liveweight gain, feed to gain ratio), nutrient digestibility and rumen fermentation.

Discontinuous delivery of ingredients or nutrients (i.e., protein supplementation, carbohydrate supplementation, etc.; Farmer et al 2004a; Farmer et al 2004b; Currier et al 2004a; Currier et al 2004b) has been investigated extensively as a mean of decreasing feeding costs. Early studies have compared blended or separate components of the ration in dairy cows (Holter et al 1977; Nocek et al 1986) but not in a discontinuous supply. In these experiments body weight gain, dry matter intake, and nutrient digestibility did not differ between TMR vs. forage fed separately of the concentrate. Similarly, Davenport et al (1983) assigned cows to a free access TMR (concentrate plus silage) or individually-fed (twice a day) concentrate and group-fed silage. These authors did not observe any differences in milk yield, and liveweight gain between feeding systems. They also measured roughage and concentrate intake, plus nutrient composition of ingested diet (i.e., CP, crude fiber [CF]) during lactation, and they did not detect any difference in intake (DM, CP, CF, and total DMD) among feeding systems. Other studies conducted by Atwood et al (2001) and Arroquy et al (2006), under conditions of free-choice diets, did not observe significant differences on average daily gain with regard to a total mixed ration. Both experiments showed a decrease in total feed intake when forage was provided separately of the concentrate. In this study, when forage was offered temporally delayed from concentrate supply, it was possible that steers might also adjust intake based on a mechanism of post-ingestive consequences, and by this way they might maintain a stable rumen environment. Thus, when they have the opportunity to choose, cattle might regulate total intake and feed ingredients, temporally and independent of ingredient proportion (Sahin et al 2003; Askar et al 2006). Also, by supplying hay every other day it might maintain a basal level of rumen fiber due to accumulation of remaining roughage among feedings (Van Soest; 1994) and to differences in forage rumen retention time respect to concentrate. Roughage rumen retention time might duplicate that of a concentrate (45 vs. 22 h for roughage and concentrate respectively; Poore et al 1990). In Trial I, unprocessed roughage fed in treatment REOD contributed to lower DMI in REOD compared to TMR. It is well known that hay processing increases total tract passage rate of roughage sources (Poore et al 1990); and as a consequence of that, in general DMI decrease and total tract digestibility increase. Thus metabolizable energy was probably increased in roughage every other day in comparison with the TMR.

Feed efficiency was higher in REOD. These results are similar to those reported by Atwood et al (2001), they observed better feed efficiency in a free-choice feeding system relative to a TMR. In a similar study, Arroquy et al (2006) observed an improvement in feed efficiency associated with a lower DMI. In agreement with these studies, in our trial the enhancement in efficiency was in concordance with a reduction in feed intake without a decrease in liveweight gain.

In Trial II, RDS did not negatively affect OM, starch, CP, and NDF intake. In previous studies conducted by Holter et al (1977) and Nocek et al (1986) compared total mixed rations with diets in which the roughage portion was delivered separately of the concentrate. In agreement with our results in those experiments, we did not observe any differences in DMI between TMR vs. feeding forage or concentrate separated from the concentrate or forage respectively. Robles et al (2007) conducted a study in which Holstein heifers were fed concentrate (ME, 2.92 Mcal/kg of DM) and barley straw (coarsely chopped to approximately 7 cm in length) in two separated feedbunks. Straw was delivered only once daily, whereas concentrate was fed in four feeding frequency treatments: one, two, three, and four times daily. In this study they did not observe differences in DMI as well as in concentrate and straw intake in response to changes in feeding frequency of the concentrate. Additionally, they did not observe differences in rumen fermentation (i.e., pH, VFA, ammonia) to concentrate feeding frequency as well.

In this study, the absence of effect on intake between feeding systems was in concordance with the lack of response in total tract digestibility, rumen pH and VFA, as well as rumen lactate. Total tract OM, CP, starch, and NDF digestibilities were not affected by RDS. Similarly, Holter et al (1977) did not observe differences between separately or blended delivery feeds in apparent digestibility (DM, CP, CF, TDN, and fat). Soto-Navarro et al (2000), in a limit-fed study conducted to evaluate feeding frequency (within a day) and intake fluctuation, did not observe differences in OM, CP, and starch digestibility between steers fed constant vs. changing amounts of feed once daily. In the scientific literature the effect of discontinuous feed delivery or feeding frequency on rumen fermentation, has been reported to be variable. Some studies found a lower rumen pH in animals fed once daily compared with animals fed more than once daily (Soto-Navarro et al 2000). Others observed that rumen pH was not affected by feeding with more frequency (Robles et al 2007). In contrast, Sutton et al (1986) and Yang and Varga (1989) reported that more meals during the day tended to decrease rumen pH, but pH was less variable.

Our findings showed that the TOA as well as the acetate to propionate ratio were similar between roughage delivery systems. Molar proportions of organic acids as well as the acetate to propionate ratio were similar to values reported in the literature (Calderon-Cortez and Zinn, 1996; Robles et al 2007). Finally, the acetate: propionate ratio was similar among diets and roughage delivery system, as well as in agreement with regular values shown in studies with high concentrate diets (Beauchemin and McGinn, 2005; Montgomery et al 2008). Although discontinuous roughage delivery might temporarily increase, rumen proportion of acetate under the condition of this study, it was not observed in the proportion of TOA among roughage delivery days. Low acetate to propionate ratio might be due to a relatively high fat content of the diet (Zinn, 1988). Inclusion of fat in high-grain rations has been pointed out to ameliorate sub acute or subclinical acidosis (Clary et al 1993).

Rumen ammonia concentration was similar in all diets and roughage delivery systems. Ammonia concentration was slightly higher in the diet with lower concentration of forage fiber. Even thought all values where close to the level of marginal ammonia concentration for rumen fermentation (> 8 mM; Hoover, 1986), digestion coefficients (OM, CP, starch, and NDF) were within the range reported for high concentrate diets.

Conclusion

Based on the results of these trials, it is concluded that steers fed a separated roughage source in a discontinuous way had similar liveweight gains, and tended to be more efficient with regard to a TMR. Total tract digestibility and rumen environmental traits (pH, VFA, and ammonia) were not affected in by the discontinuous roughage delivery relative to a TMR ration.

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Table 4. Effect of roughage delivery system (RDS) and roughage level (RL) in the diet on intake and digestibility by beef steers.

	RL, % DM			RDS[a]			
Items	**14.50**	**7.30**	**P-value**	**REOD**	**TMR**	**P-value**	**SEM[b]**
Intake, g/ kg $^{0.75}$							
OM	86.0	89.6	0.62	84.9	94.6	0.54	11.1
Starch	36.4	39.2	0.47	37.0	39.4	0.60	4.6
CP	8.8	8.1	0.82	8.6	8.8	0.76	0.6
FDN	27.6	25.5	0.88	26.6	29.8	0.63	4.2
Total tract digestion, g/ kg							
OM	630	679	0.31	655	651	0.88	24
Starch	893	827	0.32	874	882	0.73	28
CP	601	533	0.31	571	582	0.76	56
FDN	404	499	0.35	477	440	0.68	80
Total digestible OM intake, g/ kg$^{0.75}$	54.1	60.7	0.51	55.7	61.2	0.65	9.0

[a] Roughage delivery system: REOD = roughage every other day, TMR = total mixed ration.

[b] Standard error mean.

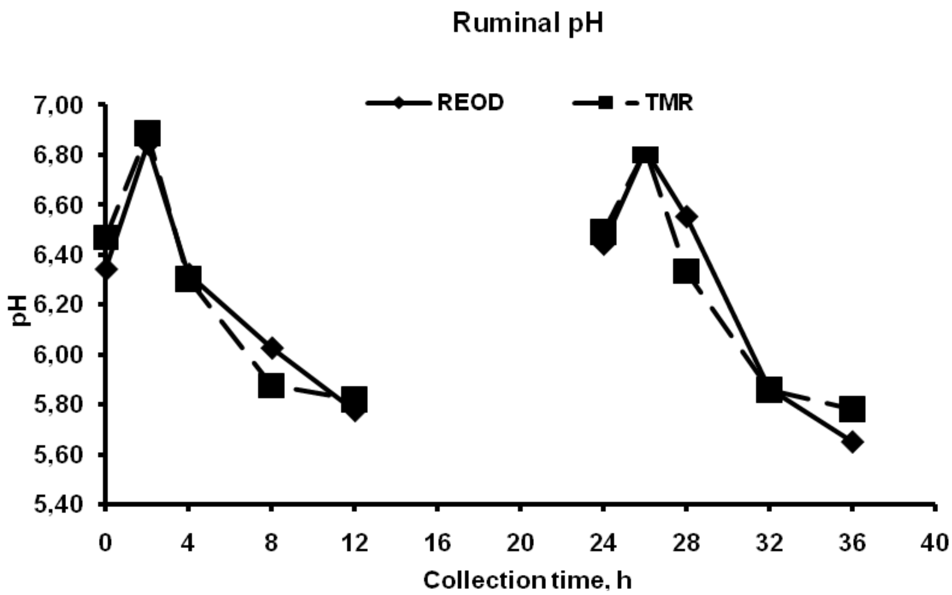
[c] Total organic acids = (acetate + propionate + butyrate + isobutyrate + valerate + lactate).

Table 5. Effect of roughage level (RL) and delivery system (RDS) on ruminal pH, ammonia and volatile fatty acids of beef steers fed a concentrate diet.

	RL, % DM			RDS[a]			
Items	14.50	7.30	P-value	REOD	TMR	P-value	SEM[b]
pH	6.32	6.20	0.48	6.26	6.25	0.99	0.10
Ammonia, mM	6.46	6.01	0.79	6.02	6.44	0.81	1.08
Total organic acids , mM[c]	89.75	70.45	0.19	80.32	79.88	0.97	8.28
Molar proportion, mol/ 100 mol							
Acetate	54.10	56.68	0.65	53.58	57.21	0.54	3.73
Propionate	26.82	22.36	0.61	27.31	21.86	0.53	5.48
Butyrate	15.83	16.90	0.75	15.88	16.85	0.77	2.14
Isobutyrate	1.00	0.96	0.85	0.93	1.02	0.28	0.07
Valerate	1.58	2.26	0.37	1.54	2.30	0.33	0.47
Lactate	0.72	0.84	0.76	0.80	0.76	0.83	0.13
Acetate: propionate ratio	2.49	2.87	0.69	2.49	2.87	0.68	0.62

[a] Roughage delivery system: REOD = roughage every other day, TMR = total mixed ration.
[b] Standard error mean.
[c] Total organic acids = (acetate + propionate + butyrate + isobutyrate + valerate + lactate).

Figure 1. Effect of roughage delivery system × collection time interaction ($P = 0.87$) on rumen pH. Standard error of the estimate of pH was 0.15. Collection times during two consecutive days were: for pH = 0, 2, 4, 8, 12, 24, 26, 28, 32, and 36 h after feeding roughage in REOD.


Ruminal pH
REOD
TMR
7,00
6,80
6,60
6,40
6,20
6,00
5,80
5,60
5,40
pH
0
4
8
12
16
20
24
28
32
36
40
Collection time, h