EFFECT OF TIME AFTER FEEDING ON DISTRIBUTION OF FEED PARTICLES IN THE GASTROINTESTINAL TRACT OF SHEEP GIVEN ORCHARDGRASS HAY ONCE A DAY

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Summary

To determine the effect of time after feeding on distribution of particle size of digesta in the gastrointestinal tract, 16 sheep given orchardgrass first cut hay were slaughtered at 2, 8, 16 and 24 hours after feeding and digesta in diverse sites of the tract were sieved into four fractions of particle size larger than 1180 μm, 300-1180, 45-300 and less than 45. Following results were obtained: 1) In the reticulo-rumen, the proportion of particles larger than 1180 μm decreased with the time after feeding, while the other particle size fractions did not change with time after feeding. 2) In the post-ruminal alimentary tract, the proportion of particles larger than 1180 μm was significantly smaller than that in the reticulo-rumen and distribution of fractions of every particle size stayed consistently at about the same level irrespective of the time after feeding. 3) In the cecum, the fraction of particle size less than 45 μm appeared to be selectively retained when the passage rate was considered.
(**Key Words**: Sheep, Gastrointestinal Tract, Feed Particle, Particle Distribution, Time After Feeding)

Introduction

One of digestion characteristics of ruminants is fermentation of fibrous fractions of feed in the rumen. To maximize the application of its characteristics to the ruminant nutrition, much works have been done on the rate of passage through the rumen, the digestion kinetics of feed particles in the rumen and the process of size reduction of feed particles in the rumen.

Poppi et al. (1980) have found that the critical size of feed particle was 1.18 mm to pass through the rumen irrespective of kinds of hay or growth stage of the plant. Particle size distribution of digesta in the abomasum has found to be very similar to that of feces. Kerley et al. (1985) have reported that the critical size was 600 to 700 μm to pass through the rumen of sheep consuming forage *ad libitum*. Obviously, degradation of fibrous matter in the rumen has been the time dependent process (Nishida et al., 1989). Results shown above, however, do not clarify the extent of contribution of each site of digestive tract to the particle reduction relating to the time elapsed after feeding.

The present study was to determine the effect of time after feeding on distribution of particle size of digesta in the reticulo-rumen, omasum, abomasum, small intestine (duodenum, jejunum and ileum), cecum and large intestine (colon and rectum) of sheep fed orchardgrass first cut hay.

Materials and Methods

Animals used were 16 mature sheep consisting of a male and 5 ewes of Suffolk, 6 ewes of Polled Dorset Horn, 3 ewes of Cheviot and an ewe of cross-bred in the flock of Takikawa Livestock Research Station. Their average live weight was 50.4 kg at slaughter. They were fed orchardgrass first cut hay chopped to 2 cm length once a day at a rate of 1.5% of live weight. Drinking water and mineral blocks were offered at free access. Feed offered was withdrawn at 2 hours after feeding and weighed. After 7-day preliminary period, behavior of active prehension

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and rumination was monitored for 24 hours using pneumograph-tambour apparatus (Okamoto, 1979). Four animals were then slaughtered at each time of 2, 8, 16 and 24 hours after feeding commenced. Digesta in the reticulo-rumen, omasum, abomasum, small intestine (duodenum, jejunum and ileum), cecum and large intestine (colon and rectum) were totally collected and weighed. Aliquot samples of digesta from each site of the digestive tracts were acidified with 5% sulfuric acid and dried in a forced-air oven at 55℃ for the analysis of chemical composition. The rest of digesta for each tract was divided into four particle size fractions by a wet sieving technique. Apertures of sieves used were 1180, 300 and 45 μm. The residues retained on each sieve were dried as described above for further analyses. The fraction less than 45 μm was calculated by subtracting the sum of residues remained on sieves from the total fraction determined in unsieved samples.

Samples of feed, sieved and unsieved fractions were ground through 2 mm screen. Dry-matter (DM) contents were determined by drying to a constant weight at 105℃. Crude protein (CP) contents were determined by kjeldahl method. Acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined by the method described by Goering and Van Soest (1970). Neutral detergent fiber (NDF) for feed sample was analyzed by the method of Goering and Van Soest (1970). Statistical analysis was done by the method described by Snedecor (1965).

Digestibility of orchardgrass first cut hay used in the present study was determined by total collection method using other 4 wethers of Suffolk. Samples of feces and feed were collected daily and made in composite samples for 5-day comparison period after 7-day preliminary period. Feeding level and methods for chemical analyses were the same as described for the slaughter experiment.

Results

One sheep slaughtered at 8 hours after feeding had abscesses as large as an egg at the cardiac region of the reticulo-rumen and in the lung. Thus, results obtained for the sheep was excluded from the analysis.

Orchardgrass hay used in the present study contained 879 g DM/kg of feed, and 83 g of CP, 728 g of NDF, 447 g of ADF and 67 g of ADL per kg of DM. Mean digestibilities with standard deviation for DM, CP, NDF and ADF were 522 ± 32, 506 ± 66, 517 ± 39 and 461 ± 45 g/kg, respectively. Acid detergent lignin was recovered in feces at the rate of 983 ± 94 g/kg of ingested. Daily intake of DM averaged 291 ± 124, 291 ± 99, 365 ± 65 and 322 ± 45 g for 4 animals slaughtered at 2, 8, 16 and 24 hours after feeding, respectively. Variation in DM intake was observed among 4 groups, but mean intakes did not differ significantly among 4 groups. Thus, daily DM intake was inferred to be the same among 4 groups. Thus, overall mean intake of DM was calculated to be 320±85 g/day. Time required for active prehension was about 120 min. for all animals because all of them were allowed to access to their feed for 2 hours before slaughter. Time used for chewing at rumination, however, increased linearly as the time to allow rumination was prolonged before slaughter.

Mean amounts of DM on the basis of DM intake were shown in fig. 1 for each alimentary tract at different times after feeding. Amounts of DM in the reticulo rumen were the greatest among the digestive tract irrespective of time after feeding. The fraction of particles larger than 1180 μm appeared to decrease with time after feeding and there was a significant difference between those at 2 and 24 hours after feeding ($p < 0.01$). Particle fractions less than 1180 μm showed no significant difference among the time after feeding. Amounts in the cecum were the second and the large intestine the third greatest among DM in diverse sites of the gastrointestinal tract. Figures 2 and 3 show mean amounts of ADF and ADL on the basis of intakes of the corresponding composition for each site of the tract at different time after feeding. Distribution patterns of ADF and ADL in the diverse tract were similar to that of DM. Particulate fractions larger than 1180 μm of ADF and ADL in the reticulo-rumen were greater at 2 hours after feeding than 24 hours ($p < 0.01$). Amounts of DM, ADF and ADL in the tract other than the reticulo-rumen showed no significant changes with time after feeding.

Percentage compositions of particle fractions for DM, ADF and ADL were shown in fig. 4 (DM), fig. 5 (ADF) and fig. 6 (ADL) for each

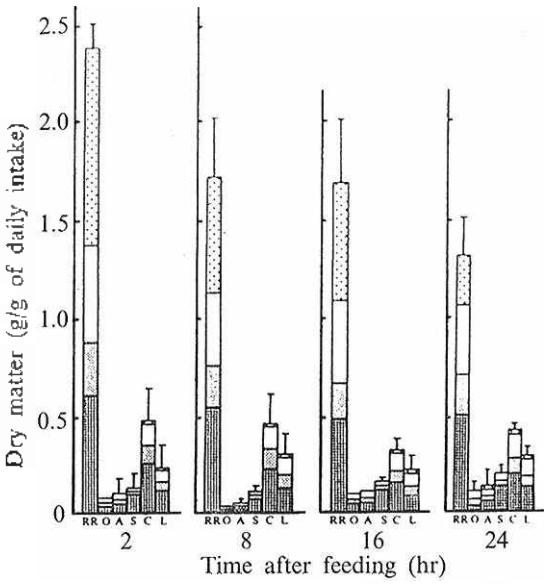

Figure 1. Changes with the time after feeding in dry matter of four sieved fractions (▨ >1180 μm, □ 300-1180, ▩ 45-300, ▦ <45 μm) on the basis of the intake (g/g) for the reticulo rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L, colon and rectum) of sheep

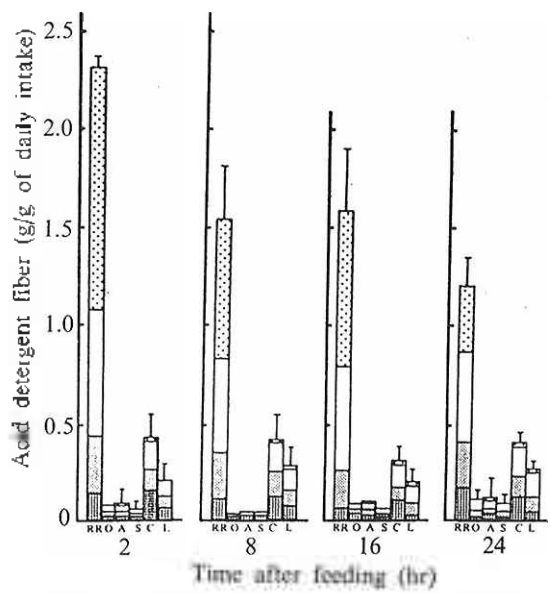

Figure 2. Changes with the time after feeding in acid detergent fiber of four sieved fractions (▨ >1180 μm, □ 300-1180, ▩ 45-300, ▦ <45 μm) on the basis of the intake (g/g) for the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep

site of the digestive tract at different slaughter time. In the reticulo-rumen, the proportion of particulate fraction greater than 1180 μm for DM, ADF and ADL tended to decrease with the time after feeding. The fractions less than 1180 μm accordingly increased with the time after feeding. The proportion of particle fractions for DM, ADF and ADL larger than 1180 μm was significantly greater at 2 hours after feeding than that at 24 hours ($p < 0.01$) in the reticulo-rumen. On the other hand, proportions of particulate fractions in the post-ruminal tract showed a little change with the time after feeding irrespective of the size of particles.

Proportions of particulate fractions larger than 1180 μm for DM, ADF and ADL were significantly greater in the reticulo-rumen than any other digestive tract irrespective of the time after feeding ($p < 0.01$), while those less than 300 μm tended to be less in the reticulo-rumen than the other tract. The pattern of percentage compositon for DM of digesta in the small intestine differed from those for ADF and ADL. The proportion of fractions less than 45 μm for DM in the small intestine increased to 75.1% which were significantly greater than those in the reticulo-rumen, omasum and abomasum ($p < 0.01$). Proportions of fractions less than 45 μm for ADF and ADL, however, did not increase in the small intestine and showed no significant difference to those in the omasum, abomasum and large intestine. Digesta in the cecum showed significantly higher proportion of the fraction less than 45 μm than those in the large intestine, while fractions of 300-1180 and 45-300 μm in the cecum were significantly lower than those in the large intestine ($p < 0.01$). Proportion of fraction larger than 1180 μm in the cecum did not differ from those in the omasum, abomasum and large intestine.

Discussion

Particulate fractions larger than 1180 μm in the reticulo-rumen decreased with the time after

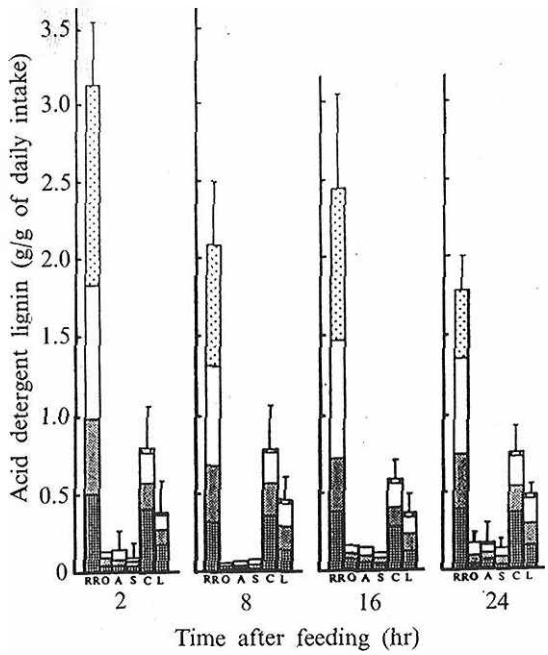

Figure 3. Changes with the time after feeding in acid detergent lignin of four sieved fractions (▒ >1180 μm, □ 300-1180, ▓ 45-300, ▤ <45 μm) on the basis of the intake (g/g) for the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep

feeding. This reduction in amounts and proportion in the reticulo-rumen may be contributed by particle size reduction through digestion in the reticulo-rumen and physical processes such as mastication. Time required for chewing (T, min.) increased with the time after feeding and negatively correlated with the particle fraction larger than 1180 μm in the reticulo-rumen (LP, g/g of intake) ($p < 0.01$). Regression analyses gave following equations for fibrous fractions:

$$\text{ADF; } LP = 1.45 - 0.0029\,(\pm 0.0004)\,T, \quad \text{s.e.} \pm 0.05,\ r = -0.86,$$

$$\text{ADL; } LP = 1.54 - 0.0028\,(\pm 0.0005)\,T, \quad \text{s.e.} \pm 0.06,\ r = -0.81.$$

The result of digestion trial showed that the recovery of ADL was over 98%. Thus, ADL fraction was inferred to be unaffected by the digestion. Regression coefficients for ADF and ADL were about the same. Physical processes such as remastication during the rumination, therefore, is inferred to have a greater influence on particle size reduction of large particles of fibrous fractions over 1180 μm than the digestion process in the reticulo-rumen. Coefficients of determinations were calculated to be 0.7 for both regression equations. McLeod and Minson (1988) have found that mastication and rumination contributed 75% of the size reduction of particles larger than 1180 μm in the rumen of cattle fed

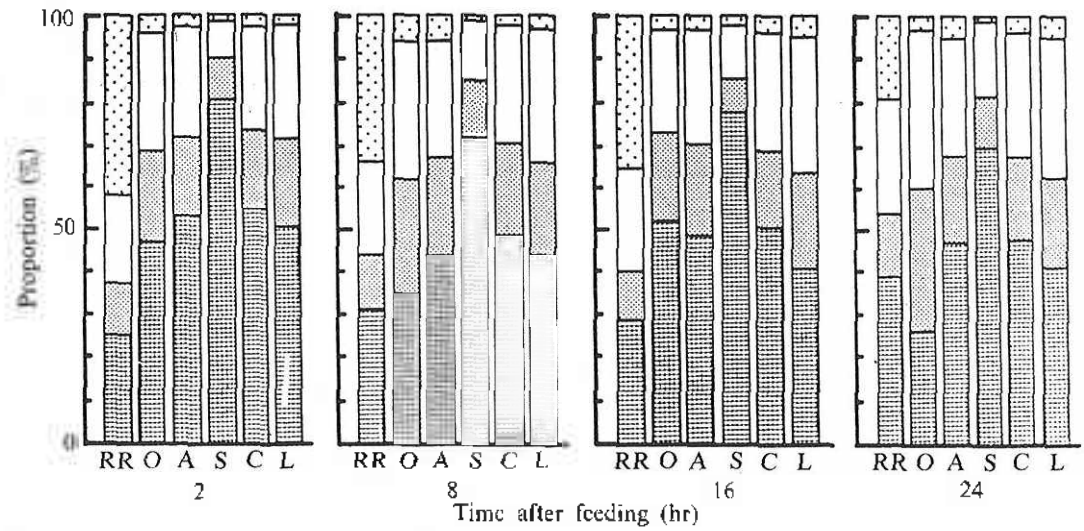

Figure 4. Changes with the time after feeding in dry-matter percentage of four sieved fractions (▒ >1180 μm, □ 300-1180, ▓ 45-300, ▤ <45 μm) for the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L, colon and rectum) of sheep

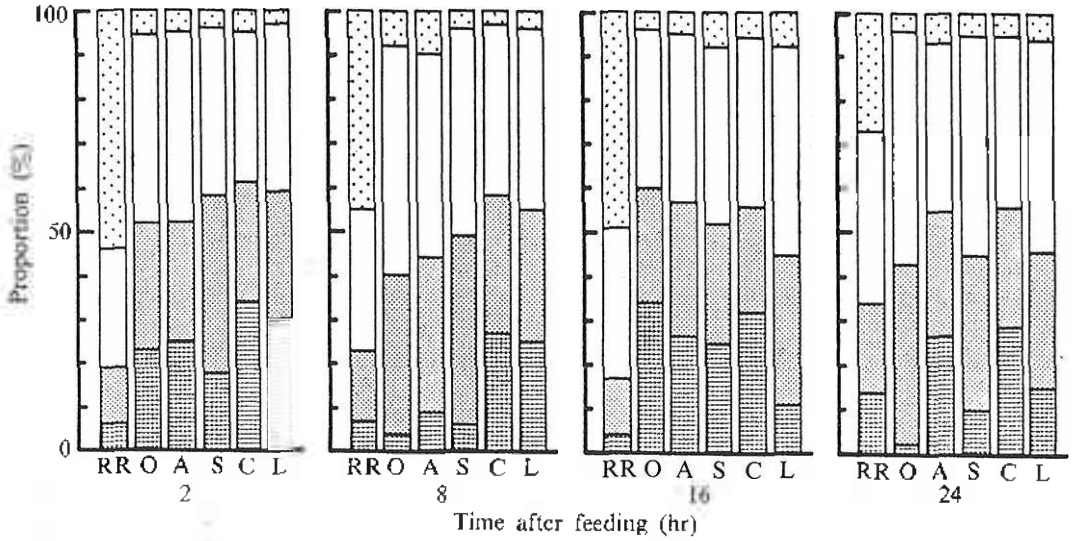

Figure 5. Changes with the time after feeding in acid detergent fiber percentage of four sieved fractions (>1180 μm, 300-1180, 45-300, <45 μm) for the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep

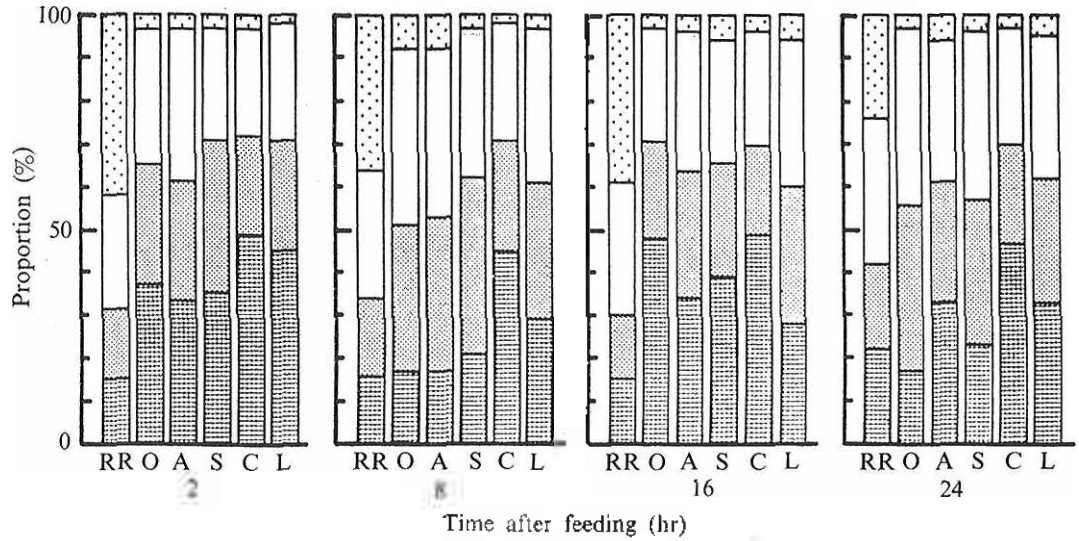

Figure 6. Changes with the time after feeding in acid detergent lignin percentage of four sieved fractions (>1180, 300-1180, 45-300, <45 μm) for the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep

ryegrass or alfalfa hay. It may, therefore, be suggested that the physical process such as mastication contributes over two third of size reduction of particles larger than 1180 μm in the reticulo-rumen of ruminants.

The distribution of particle fractions of 300-1180, 45-300 and less than 45 μm was not influenced by the time after feeding. Thus, pools for these fractions may have a balance between inflow from a pool of larger particles than a given size and outflow to a pool of smaller particles than the corresponding size and/or to

the lower gut.

Assuming that the daily inflow and outflow of ADL to a given site of the tract (wt) were the same as daily intake of ADL, mean retention time for each site of the tract (RT, hr) was calculated using a measured ADL pool in a given site of the tract (Wt) as follows: RT = (Wt/wt) ×24. Furthermore, ADL pools of four particulate fractions in each site of the tract were expressed as W1 for that in particles larger than 1180 μm, W2 for 300-1180, W3 for 45-300 and W4 for those less than 45. Assuming proportions of particle fractions for ADL passing from the reticulo-rumen(d_x) to be the same as those in the omasum and abomasum, or those from the cecum the same as those in the large intestine, rate constants of passage for each fraction in the reticulo-rumen and the cecum were calculated using following equations:

Rate constant for the fraction larger than 1180 μm (k_1);

$$k_1(hr^{-1}) = (wt \cdot d_1)/Wt \times 1/24$$

Rate constant for the fraction of 1180-300 μm (k_2);

$$k_2(hr^{-1}) = (wt \cdot d_2)/Wt \times 1/24$$

Rate constant for the fraction of 300-45 μm (k_3);

$$k_3(hr^{-1}) = (wt \cdot d_3)/Wt \times 1/24$$

Rate constant for fraction less than 45 μm (k_4);

$$k_4(hr^{-1}) = (wt \cdot d_4)/Wt \times 1/24$$

Table 1 shows results calculated. Mean retention time of the reticulo-rumen was the largest and occupied over 60% of RT totaled for the whole tract. In the lower gut, RT for the omasum, abomasum and small intestine showed the same length. Digesta in the cecum and the large intestine stayed for 18 to 10 hours in the corresponding tract, respectively. Thus, the passage of feed through the digestive tract may be determined by the rate of passage through the reticulo-rumen and cecum. Results of rate constants for four particulate fractions show that particles larger than 1180 μm are required to reduce the size to pass through the reticulo-rumen with the same rate as those less than 1180 μm, while in the cecum the fraction less than 45 μm requires more time than those for larger particles. Therefore, it is inferred that particles larger than 1180 μm are selectively retained in the reticulo-rumen and those less than 45 μm in the cecum.

TABLE 1. MEAN RETENTION TIME OF DIGESTA IN THE DIGESTIVE TRACTS AND PASSAGE RATE CONSTANTS FOR FOUR SIEVED FRACTIONS IN THE RETICULO-RUMEN AND CECUM

	Mean retention time (hr)	Passage rate constants (%/hr) for particles of			
		>1180 μm	300-1180 μm	45-300 μm	<45 μm
Reticulo-rumen	57.0±15.8	0.36[a][1]±0.22	2.25[b]±0.83	3.17[b]±1.09	3.19[b]±1.36
Omasum	2.9± 1.5	–[2]	–	–	–
Abomasum	3.1± 2.5	–	–	–	–
Small intestine	2.5± 1.5	–	–	–	–
Cecum	17.6± 5.0	8.63[a] ±5.36	7.59[a]±2.27	7.85[a]±2.61	4.44[b]±1.59
Large intestine (colon and rectum)	10.0± 3.4	–	–	–	–

[1] Figures with different superscripts in the same row are significantly different ($p < 0.01$).
[2] Not calculated.

There were no significant differences in particle distribution at each post-ruminal tract among the time after feeding. Dry-matter pools less than 45 μm tended to be higher than corresponding fibrous pools in any site of the tract. Especially, DM pool less than 45 μm was significantly greater than fibrous pools in the small intestine. The DM pool may include microorganisms from the rumen, debris of epithelial cells exfoliated from the surface of the alimentary tract and digestive enzymes. These fine particulates are inferred to contribute to a higher proportion of the DM fraction less than 45 μm in the small intestine. Thus, the change in fibrous fractions which are not influenced by the endogenous substances should be considered when the analysis is to be carried out on size reduction process and distribution of feed particles in the alimentary tract.

Distribution and proportion of particles of fibrous fractions did not differ significantly among the omasum, abomasum, small intestine and large intestine irrespective of the time after feeding. Particles of fibrous fractions may not reduce in their size in these organs. The proportion of particles less than 45 μm were significantly higher in the cecum than in those four organs described above, while that of particles over 45 μm tended to be smaller in the cecum than in four organs. The rate constant for passage of particle fractions over 45 μm was about double of that of the fraction less than 45 μm in the cecum. Thus, it is inferred that the cecum selectively retains fine particles of fibrous fractions to assist fermentation by microorganisms in it. This inference is also supported by the estimation described below.

To estimate digestion of fibrous materials in diverse sites of the alimentary tract, digestibilities of ADF at diverse sites of the tract were estimated using ADL as an index and plotted in conjunction with RT for each site of the tract (fig. 7). The calculated digestibility of ADF at the cecum and large intestine well agreed with that determined by the digestion trial. Assuming the results obtained in the cecum and large intestine being digestibility of ADF in the whole tract, figure 7 shows that ADF digested in the reticulo-rumen for 57 hours contributes to about 80% of ADF digested in the whole tract and 20% in the cecum. The digestion of ADF appears to have less importance or to take place little in the omasum, abomasum, small intestine and large intestine.

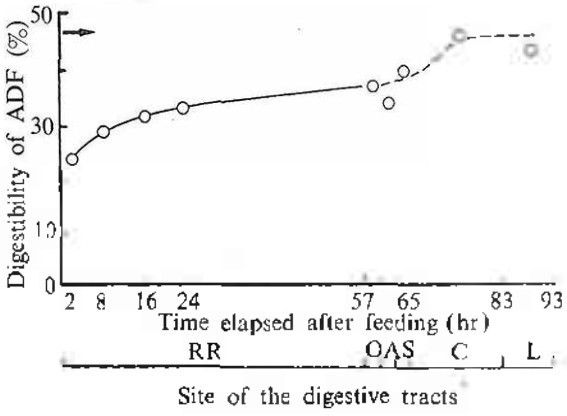

Figure 7. Digestibility of ADF in the reticulo-rumen (RR), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L, colon and rectum) in conjunction with mean retention time for each site of the tract.
Digestibilities of the post-ruminal tracts were calculated by pooled results. The arrow shows ADF digestibility determined by the digestion trial. Solid lines is drawn by the regression equation: $Y = 22.3X^{0.126}$ and broken line by inspection

From the results and discussion above, it is concluded that there is no influence of time after feeding on distribution of particulate fractions of digesta in the post-ruminal tract, while that of particles larger than 1180 μm in the reticulo-rumen decreases with the time after feeding without changing the distributions of particle fractions less than 1180 μm.

Acknowledgements

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