

Studies on analysis of passage rates of digesta in ruminants fed roughage.

Forage constitutes the major portion of the diets of livestock, especially ruminants. Ruminants, with their specially designed digestive systems and associated microbial populations, are well adapted for obtaining nutrients and energy from forage. The establishment of feed management systems for various types of forage is needed for optimal animal production. Furthermore, the development of high quality self-sufficient feed production systems is needed for the establishment of sustainable agriculture.

The voluntary intake and nutritive value of forage are key factors affecting the productivity of ruminants. Both of these factors are strongly affected by the passage of digesta from the rumen. It is thought that roughage ingested by a ruminant is reduced in particle size so as to be of sufficiently small size to be able to pass through the reticulo-omasal orifice by mastication in eating and ruminating time or by digestion of microbes in the rumen. Measurement of the passage rates of roughage through the digestive tract of a ruminant provides useful information for elucidation of the process of digestion and the control mechanism of the voluntary intake of ruminants. However, the passage rate of roughage through the digestive tract of a ruminant is affected by many plant and animal factors and by interactions between those factors, and the relationships between those factors are complex. Moreover, there is currently no established technique using rare earth elements as particulate phase markers for measurement of the passage

rates of digesta in ruminants.

The objective of the present study was to assess the usefulness of rare earth elements as particulate phase markers for the estimation of passage rates of digesta in sheep fed roughage and to clarify the effects of forage factors on passage rates and the relationship between passage rates of digesta and digestibilities or chewing activity, which is closely related to reduction of forage particle size.

1. Evaluation of rare earth elements as particulate phase markers for the estimation of passage rates of digesta in wethers fed roughage

1) *Comparison of labeling methods of rare earth elements for estimating passage rates in wethers fed roughage*

Rare earth elements are widely used as particulate markers because they possess an affinity for particulate matter and because they are indigestible, quantitatively excreted, and can be readily analyzed by several methods. Two labeling methods (the spray technique and immersion technique) are generally used for measurement of passage rates of digesta in ruminants.

Eighteen wethers fed one of seven forages were simultaneously dosed with ytterbium (Yb)-labeled hay by spraying and with dysprosium (Dy)-labeled hay by immersion as particulate phase markers. There were high correlations between passage parameters estimated by the spraying technique and those estimated by the immersion technique. There was no difference between the values of ruminal passage rate (k_1) obtained by the

two methods, but the post-ruminal passage rate (k_2) was greater and the transit time (TT: time of the first appearance of a marker in feces) and total mean retention time (TMRT) were shorter when measured using forage prepared by the spraying method. These results indicated that the dissociation rate of rare earth elements from original labeled feed material in digestive tract was less when the feed was labeled by the immersion technique than by the spray technique.

2) *Passage rate of rare earth-labeled hay or neutral detergent fiber in wethers fed roughages*

Several researchers recommend the use of neutral detergent fiber (NDF) of forage labeled with a rare earth element as a particulate phase marker for estimation of the passage rates of digesta, because a neutral detergent solvent removes only small amounts of the rare earth element applied to forage fiber prepared by the same solvent. On the other hand, many researchers use rare earths applied directly to forage as particulate phase markers.

Eleven wethers were used in experiments to evaluate rare earth-labeled hay and its NDF as a particulate phase marker for estimation of passage rates. The rate constant k_1 estimated from Yb-labeled NDF was significantly lower than the rate from Dy-labeled hay, particularly when wethers were fed alfalfa hay. There was no difference in k_2 and TT between rare earth labeling sources. There were high positive correlations between k_1 estimated from Dy-labeled hay and the passage rate of the liquid phase calculated from fecal Co excretion curves. These results suggested that the behavior of rare earth-labeled NDF was different from that of rare earth-labeled hay in the digestive

tract of ruminants.

3) *Comparison of chromium oxide and rare earths as particulate phase markers for estimation of digesta passage rate in wethers*

Chromic oxide (Cr_2O_3) and rare earths are widely used as indicators of digestion or as passage markers. However, there is little information available concerning the behavior of these materials in the digestive tract of ruminants.

Twelve wethers were used to evaluate Cr_2O_3 and rare earth-labeled feedstuff (Dy-labeled for timothy hays and Yb-labeled for soybean meal) as particulate phase markers for estimation of the passage rate of digesta. The distributions of Dy, Yb and Cr in three fractions (47 μm mesh residue, fine feeds and microbial residue, and supernatant) of ruminal and abomasum digesta at 6 and 24 hours after dosing were determined. Retention of Cr in the rumen at 24 hours after dosing varied among wethers. Less than 1% of Cr was recovered in supernatant. Percentages of Dy and Yb released into the supernatant from the originally labeled hay and soybean meal were 1-3% and 3-14%, respectively. There were large differences among individual sheep in the residual rate of Cr in the reticulo-rumen. Ruminal passage rates (k_1) estimated from fecal Cr excretion curves were significantly faster than those estimated using Dy-labeled hay and Yb-labeled soybean meal. No significant differences were observed between the values of k_1 of Cr in wethers fed seed setting hay and those fed heading hay. However, there were significant differences in k_1 values estimated from Dy-labeled hay according to the maturity of hay. These results suggested that the behavior of the rare earths

in the rumen was different from that of Cr_2O_3 .

These results indicate that rare earth-labeled hay shows a more accurate reflection of the behavior of digesta in the digestive tract and that rare earth elements are more suitable as particulate phase markers than Cr_2O_3 . It is concluded that the measurement of passage rates using the rare earth elements as particulate phase markers is very useful for the analysis of digestion dynamics in ruminants.

2. Elucidation of the effects of forage factors on passage rates and the relationship between passage rates of digesta and digestibility or chewing activity which is closely related to the reduction of forage particle size

1) *Effects of the maturity of timothy hay on chewing time and passage rate of digesta in wethers*

The chewing behavior, which is thought to be the main factor affecting particle size reduction of ingested roughage, and passage rates of digesta in twelve wethers fed timothy hay of three different maturities (at preheading, heading and seed setting) at the same intake level were compared. The daily time spent ruminating was significantly shorter in the case of preheading hay than in the case of heading or seed setting hay. There were no differences in the ruminal liquid passage rates of the three hays. However, the ruminal particulate passage rate calculated from fecal Dy excretions of setting hay was significantly slower than that of preheading hay. The total mean retention time for seed setting hay was longer than that for preheading and heading hays. The results showed that the maturity of timothy hay affects

the ruminal passage rate and suggested that ruminal passage of digesta is closely related to physical particle reduction.

2) *Effects of soybean meal supplement on digestibility, chewing time, and passage rates of digesta in wethers fed timothy hay*

Soybean meal (SM) supplement increased apparent digestibilities of acid detergent fiber, neutral detergent fiber and cellulose in wethers fed heading-stage hay. There was no difference between digestibilities of hemicellulose in wethers given SM supplementation and those given no SM supplementation. The ruminating time and total chewing time of wethers fed either heading or seed setting timothy hay were significantly decreased by SM supplementation. However, no significant differences were observed between ruminal liquid or particulate passage rates in wethers given SM supplementation and those not given SM supplementation. These results showed that nitrogen supplementation improved digestion of forage fiber but did not affect the rate of passage of particulate digesta through the rumen.

3) *Effects of species and physical form of forage on chewing time and passage rates of digesta*

The physical form and species of forage are thought to affect chewing time and passage rates. When wethers were fed long sorghum silage, the chewing time and ruminal and total mean retention time were longer than when they were fed short sorghum silage. However, in the case of corn silage, no significant effects of chopping length on ruminating time or particulate passage rates were observed. The results showed that effects of chopping

length of forage on chewing activity and passage rates of digesta in ruminants vary with the forage species. The decreases in digestibilities of ADF and NDF with increases in dry matter intake (DMI) in wethers fed alfalfa hay cubes were larger than those in wethers fed chopped timothy hay. At a low intake level, eating and ruminating times per day of wethers fed timothy hay were similar to those of wethers fed alfalfa hay cubes. In contrast, wethers fed timothy hay at a high intake level spent more time eating and ruminating than did sheep fed alfalfa hay cubes. Particulate passage rates in wethers fed alfalfa were greater than those in wethers fed timothy hay at a similar intake level.

These results indicated that the effects of intake level on chewing time and particulate passage rate vary with the forage species and suggested that the ruminal particulate passage rate is closely related to the ease of particle size reduction depending on the histological structure of the forage.

4) *Analysis of the factors affecting passage rates in wethers fed roughages.*

From statistical analysis of the relationship between ruminal passage rate and DMI using data from 70 wethers, it was statistically confirmed that ruminal passage rates vary with the forage species, and that the ruminal passage of alfalfa in wethers was greater than that of grass at a similar intake level. Ruminal retention time (y) was found to be significantly correlated with DMI (x_1) and NDF digestibility or ADF digestibility (x_2). The equations are as follows.

$$y = 51.57 - 0.601x_1 + 0.213x_2 \quad (x_2: \text{NDF digestibility, } R^2=0.575 \text{ (} p < 0.01 \text{)})$$

$$y = 49.65 - 0.593x_1 + 0.238x_2 \quad (x_2: \text{ADF digestibility, } R^2=0.570 \text{ (} p < 0.01 \text{)})$$

These results indicate that the passage rate of digesta in wethers fed roughage is related to DMI and the digestibility of fibrous contents.

In conclusion, the passage rate of digesta in ruminants fed roughage varies according to the kinds of roughage source and is strongly affected by the ease of particle size reduction of digesta, which is closely related to the morphology of the plant and the physico-chemical structure of the cell wall.