The Particle Size Distributions of Ingested Boli, Rumen Digesta and Feces in Sheep Fed Orchardgrass Hay Harvested at Different Stages of Maturity

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Abstract The changes in particle size distribution of ingested boli, rumen digesta and feces were investigated with four rumen cannulated sheep receiving 3 varieties of orchardgrass hay (H1, H2 and H3) once a day. The hay was harvested at three stages of maturity: pre-heading; a 1:1 heading to blooming ratio; and a 1:1 blooming to fruiting ratio for H1, H2, and H3, respectively. The digestion coefficients and voluntary intake for hay decreased with advancing stage of maturity. The sheep were fed 1300 g of the unchopped hay for 3 h a day and representative samples of total rumen digesta were collected at 3, 7, 11, 15, 19 and 24 h after feeding. The particle size distribution of every sample was determined by the wet-sieving technique and expressed as the dry matter proportion of large particles (LP, retained on 5600, 2360 and 1180 µm sieves), small particles (SP, passed through a 1180 µm sieve and retained on 47 µm sieves) and soluble fraction (SOL, passed through a 47 µm sieve) to total sample dry matter. The percentage of LP in the ingested boli was higher for H1 than for H2 or H3. The percentage of the boli-particles retained on a 5600 µm sieve was prominently higher for H1, as compared to that for the other hay varieties. The percentage of LP in the rumen digesta decreased from 46% at 3 h after feeding to 13% at 24 h for H1, 39 to 14% for H2 and 34 to 8% for H3, respectively. However, the percentage of ruminal LP at each sampling time tended to be higher for H1 than for H2 and H3, although the difference was not so marked. The percentage of SP increased from 28% at 3 h after feeding to 47% at 24 h for H1, 35 to 62% for H2 and 47 to 68% for H3, respectively. The percentage of ruminal SP was higher (P<0.05) for H2 and H3 than for H1 at every sampling time. The percentage of SOL in the rumen digesta tended to increase with time after feeding (from 26% at 3 h to 41% at 24 h) for H1, whereas it showed no change with time and accounted for about 25% of total digesta for H2 and H3. The percentages of LP in feces were very low for the three hay varieties. The percentage of SP in feces for H3 was higher (P<0.05) than for either H1 or H2, and inversely, SOL was lower (P<0.05) for H3 than for the other hay varieties.

Key words: orchardgrass hay, particle size distribution, sheep

It is well known that differences in forage maturity govern cell wall constituents and physical characteristics, which in turn influence voluntary intake and digestibility. Size and rates of size reduction for ingested forage particles are thought to be important factors which closely relate to the rate of ruminal passage and ruminal digestion\textsuperscript{10,11,20}. Accordingly, differences in the stage of forage maturity seem to cause the differences in size of forage particles entering the rumen, size reduction, digestion and passage. MERTENS and ELY\textsuperscript{10} and MERTENS et al.\textsuperscript{12} emphasized that characterizing the particle size distribution of digesta was critical for researching the dynamics of digesta particles in the rumen.

The present study focuses on the influence of orchardgrass hay maturity stage on the changes in particle size distribution of rumen digesta with time after feeding, and the particle size distribution of ingested boli and feces determined with four ruminally cannulated sheep under once-a-day feeding. The orchardgrass hay varieties used in this study were harvested at three stages of maturity to provide the differences in cell wall constituents, voluntary intake and digestibility.

**Materials and Methods**

**Feeds:** Three 1st cut orchardgrass hay varieties (H 1, H 2 and H 3) were prepared. The hay was harvested at three stages of maturity: pre-heading; a 1:1 heading to blooming ratio; and a 1:1 blooming to fruiting ratio, for H 1, H 2 and H 3, respectively.

**Animals and feeding:** Four 3-year-old wethers were used, weighing 68 kg on average, which were fitted with a large ruminal cannula (75 mm o.d.). The sheep were individually kept in a metabolism crate with constant light and had free access to water and mineral blocks. The sheep were fed hay in the long form for 3 h a day. The quantity of feed was 1300 g (as is) for H 1, H 2 and H 3, respectively. H 1, H 2 and H 3 hay were offered to the sheep successively. The feeding period for each hay was 42 d of which the first 7 d were for adaptation. The measurements were carried out for the last 35 d.

**Measurements:** During the 35 d measurement period, determinations were made for total tract digestibility, eating and rumination behavior, particle size distribution of ingested boli, and rumen digesta with time after feeding and feces.

The digestion coefficients of hay were determined by the total collection method. Samples of the hay, refusals and feces were collected daily and made into composite samples for a 5 d collection period after the 7 d-adaptation period. A part of the fecal sample was taken to determine particle size distribution. The other samples were dried in a forced-air oven at 60°C for 72 h and ground to pass through a 1 mm screen in a Wiley mill for chemical composition analysis.

On d 10 through d 12 of each measurement period, the time spent eating and ruminating was measured by recording behavior for 1 min at intervals of 5 min for three consecutive days.

On d 13 through d 30 of each measurement period, total rumen digesta were manually evacuated via the rumen fistula. Total digesta were weighed, mixed and sampled (400 g). The remainder were returned to the rumen. The whole process took less than 30 min per animal. In order to overcome any effects of the rumen evacuation of subsequent measurements, a minimum interval of 72 h was allowed between each evacuation. Digesta samplings were conducted at 3, 7, 11, 15, 19 and 24 h after feeding of days 13, 17, 20, 23, 26 and 30, respectively.

Collection of the ingested boli was conducted after the total evacuation of rumen digesta 24 h after feeding. The bolus sample (300 g) was collected manually from the cardiac opening. Samples of ingested boli, rumen digesta and feces for determining particle size distribution were stored at 4°C until analysis.
Voluntary intake of the three hay varieties was determined successively for H1, H2 and H3 using four intact adult sheep with a mean weight of 78 kg. The feeding period for determining voluntary intake was 21 d; 7 d for adaptation and 14 d for measurement. Hay were offered to the sheep twice a day (08:00 and 20:00) in sufficient amounts to ensure voluntary intake (10% refusal).

Analyses: The particle size distribution of each sample was determined by the wet-sieving technique. The screen openings of the sieves (20 cm i.d.) used were 5600, 2360, 1180, 600, 300, 150 and 47 µm for ingested boli and rumen digesta, and 1180, 600, 300, 150 and 47 µm for feces. The particle size distribution of every sample was expressed as a percentage of the dry matter (DM) retained on each sieve to the total sample DM. As described previously\(^5\), particles were grouped into the three fractions; large particles (LP, retained on 5600, 2360, and 1180 µm sieves), small particles (SP, passed through a 1180 µm sieve and retained on 600, 300, 150 and 47 µm sieves) and soluble fractions (SOL, passed through a 47 µm sieve).

The DM contents of ingested boli, rumen digesta and feces were determined for fresh materials by drying at 60°C for 48 h. Samples of the hay, refusals and feces were analyzed for DM, crude ash and crude protein (CP) via the method of A.O.A.C.\(^1\), and for neutral detergent fiber (NDF) and acid detergent lignin (ADL) via the procedure of \textit{Goering} and \textit{Van Soest}\(^3\).

Results were subjected to a one-way layout design with the three stages of hay maturity as a factor. Statistical analyses were conducted by an analysis of variance, and the differences in means for the three treatments were tested using Tukey's procedure\(^21\).

### Results and Discussion

The differences in hay maturity stage resulted in differences in chemical composition, digestion coefficients and voluntary intake (Table 1). By advancing the stage of maturity, CP content decreased whereas NDF and ADL content increased, as expected. All digestion coefficients for H1 were the highest and those for H3 were the lowest. The decrease in organic matter digestibility with ad-

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<th>Table 1. Chemical composition, digestion coefficients and voluntary intake of the hays (H1, H2, and H3) harvested at different stages of maturity</th>
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<tr>
<td>Composition (% dry matter)</td>
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<tr>
<td>Crude protein</td>
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<td>Neutral detergent fiber</td>
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<td>Digestibility (%)</td>
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<tr>
<td>Neutral detergent fiber</td>
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<td>Voluntary intake (% body weight)</td>
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\(^1\) Harvested at the pre-heading stage.
\(^2\) Harvested at the stage of maturity heading to blooming ratio 1:1.
\(^3\) Harvested at the stage of maturity blooming to fruiting ratio 1:1.

* Mean values with their standard deviations for four sheep.

\(a, b, c\) Means within the same row with different superscripts differ (P<0.05).
Advancing maturity was associated with a reduction in CP and corresponding increase in NDF and ADL. Voluntary intake was significantly higher (P<0.05) for H1 than for the other hay varieties.

Dry-matter intake, daily time spent eating and ruminating in the cannulated sheep are summarized in Table 2. The daily allowance was consumed within 3 h for H1 and H2. Orts were observed in all sheep fed on H3. The daily time spent eating was significantly shorter (P<0.05) for H1 than for H2 and H3. The daily time spent ruminating was significantly longer (P<0.05) for H3 than for H1 and H2.

The particle size distributions of the ingested boli are shown in Fig. 1. The percentage of LP in the boli was more than 60% for all hay varieties, and was significantly higher (P<0.05) for H1 than for H2 and H3. Inversely, the percentage of SP was higher for H2 and H3 than for H1. The percentage of SOL in the boli, which represents the solubility of feed DM during eating2, was almost the same for all the hay varieties. The difference in the LP% between each hay was prominent. This difference was attributable to the difference in the particles retained on a 5600μm sieve. The percentage of particles retained on a 5600μm sieve was 58.8, 48.6 and 46.4% for H1, H2, and H3, respectively, and was significantly higher (P<0.05) for H1 than for either H2 or H3. Several researchers have also reported that as the fiber content of the chopped forage diet increased, the animal chewed more to form a bolus4,9 and gave a bolus of smaller particle size4,6,15). The NDF content and daily time spent eating per kg DM were greater for H2 and H3 than for H1 (Table 1 and 2). Since animals fed on H1 easily formed a bolus acceptable for deglutition, the percentage of particles retained on a 5600μm sieve might have been higher for H1 than for the other hay varieties.

The particle size distribution of total rumen digesta at each sampling time is shown in Fig. 2. The percentage of LP in the rumen digesta decreased from 46% at 3 h after feeding to 13% at 24 h for H1, 39 to 14% for H2 and 34 to 8% for H3, respectively. These findings basically agree with those reported by other researchers4,5,13,18,19), who fed grass and legume hay to sheep once a day. Although the LP% at each

**Table 2.** Dry matter intake, time spent eating and rumination in sheep fed on the hays (H1, H2 and H3) harvested at different stages of maturity once a day

<table>
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<th>H1</th>
<th>H2</th>
<th>H3</th>
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<tr>
<td>Dry matter intake (g/d)</td>
<td>1090±0</td>
<td>994±52</td>
<td>876±41</td>
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<tr>
<td>Daily time spent eating (min)</td>
<td>93±22</td>
<td>134±18</td>
<td>139±12</td>
</tr>
<tr>
<td>Time spent eating kg DM (min)</td>
<td>95±17</td>
<td>135±21</td>
<td>156±23</td>
</tr>
<tr>
<td>Daily time spent ruminating (min)</td>
<td>399±78</td>
<td>399±58</td>
<td>498±59</td>
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* For details of the hays, see footnote in Table 1.

** Mean values with their standard deviations for four sheep.

* a,b Means within the same row with different superscripts differ (P<0.05).

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Fig. 2. Changes in particle size distribution of rumen digesta with time after feeding in sheep fed hays (H1, H2 and H3) harvested at different stages of maturity. Mean values for four sheep. For details of the hays, see footnote in Table 1.

- the percentage of large particles (LP, retained on ≥1180 μm sieves);
- the percentage of small particles (SP, passed through a 1180 μm sieve and retained on ≥47 μm sieves); and
- the percentage of soluble fraction (SOL, particles passed through a 47 μm sieve).

Sampling time tended to be higher for H1 than for the other hay varieties, the differences were not so great. The diurnal change in the LP% of total rumen digesta may be caused by many factors; e.g., weight loss of LP through ruminal digestion and size reduction of LP during rumination and ruminal passage of digesta particles, therefore, changes in the proportions of LP sub-fractions are presented to investigate in detail the difference in LP% among hay varieties. The proportions of LP sub-fractions, retained on 5600, 2360 and 1180 μm sieves, differed significantly (P<0.05) between each hay (Fig. 3). The proportions of particles retained on a 5600 μm sieve in the ruminal LP fraction were significantly higher (P<0.05) for H1 than for H2 and H3 for all measurements. The daily time spent ruminating contributes considerably to the reduction of ruminal LP. The time spent ruminating was significantly longer (P<0.05) for H3 than for H1, and H2 was to some extent higher than H1, as shown in Table 2. The difference in the

Fig. 3. Changes in proportion of three sub-fractions of the ruminal large particles with time after feeding in sheep fed hays (H1, H2 and H3) harvested at different stages of maturity. Mean values for four sheep. For details of the hays, see footnote in Table 1.

- the proportion of particles retained on a 5600 μm sieve;
- the proportion of particles passed through a 5600 μm sieve and retained on a 2360 μm sieve; and
- the proportion of particles passed through a 2360 μm sieve and retained on a 1180 μm sieve.
proportion of digesta particles retained on a 5600 µm sieve suggests that the breakdown extent of ruminal LP during rumination might have been higher for H3 and H2 than for H1.

In contrast to the decreasing pattern of ruminal LP%, the percentage of SP in the rumen digesta increased from 28% at 3 h after feeding to 47% at 24 h for H1, 35 to 62% for H2 and 47 to 68% for H3, respectively (Fig. 2). The percentage of ruminal SP was significantly higher (P < 0.05) for H2 and H3 than for H1 at every sampling time. Ruminal SOL as a percentage tended to be higher for H1 than for H2 and H3. The percentage of SOL in the rumen digesta increased with time after feeding (from 26% at 3 h to 41% at 24 h) for H1, whereas it did not change with time after feeding, and accounted for about 25% of total digesta for H2 and H3. The ruminal SOL fraction consists of very fine particles (less than 47 µm) and solubilized or digested material. However, we did not divide the SOL fraction into very fine particles and soluble material, so the increase in ruminal SOL with time after feeding for H1 is attributed to the higher ruminal-degradability of digesta particles for H1 than for H2 and H3. Both SP and SOL were smaller than the size considered to be critical for ruminal passage17. The proportion of SP and SOL accounted for more than half of the total rumen digesta at any sampling time for all hay varieties, and tended to increase with time after feeding. This result is consistent with other studies5,13. As suggested by OKAMOTO et al16, the size of digesta particle may not be the absolute determinant for regulating ruminal passage.

The particle size distributions of feces are shown in Fig. 4. The percentages of fecal particles larger than the critical size17 accounted for only 0.7 to 3.7%, and the values did not differ significantly (P > 0.05) between each hay. The percentage of SP in feces was 48.8, 53.2 and 70.3% for H1, H2 and H3, respectively, and was significantly higher (P < 0.05) for H3 than for either H1 or H2. Inversely, the percentage of SOL in feces was 50.5, 43.2 and 28.3% for H1, H2 and H3, respectively, and the value for H3 was significantly lower (P < 0.05) than those for H1 and H2. In contrast to the fecal particle size distribution for H1, the percentage of fecal SOL was lower compared to fecal SP in sheep fed on H2 and H3. Although the SP:SOL ratio in the feces differed markedly between H2 and H3, there was a slight resemblance in the fecal particle size distribution between each hay. Since digesta particle size was reduced only slightly between the omasum and the rectum17, the particle size distribution of feces is thought to be a good estimate of particle size distribution for digesta passing through the rumen. The difference observed in fecal particle size distribution between each hay showed that the rumen-passed particles were relatively small for H1 compared to H2 and H3 hays. This could be attributed to a higher proportion of ruminal SP passing through the rumen than is solubilized by microbes.

From the above results, it is suggested that the extent of particle size reduction during eating and rumination in sheep fed on early-

![Fig. 4. Partile size distribution of feces in sheep fed hays (H1, H2 and H3) harvested at different stages of maturity. Mean values for four sheep. For details of the hays, see footnote in Table 1. LP, particles retained on a 1180 µm sieve; SP, particles passed through a 1180 µm sieve and retained on ≈47 µm sieves; and SOL, soluble fraction (particles passed through a 47 µm sieve).]
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harvested orchardgrass hay is lower than for sheep fed on late-harvested hay, whereas the degradability of ruminal digesta particles seems to be higher for early-harvested hay than for late-harvested hay. In addition, it is also suggested that hay maturity has an effect on the size distributions of particles passing through the rumen.

Acknowledgement

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References

20) WESTON, R.H. and P.M. KENNEDY, Various aspects of reticulorumen digestive function in relation to diet and digesta particle size. in Techniques in particle size analysis of feed and
刈取り期の異なるオーチャードグラス乾草を1日1回給与した
めん羊における喰下食塊、反芻胃内容物および
糞の粒度分布

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刈取り期の異なるオーチャードグラス1番刈り乾草3種類（H1、出穂前；H2、出穂；開花＝1:1:H 3、開花：結実＝1:1）を、ルーメンカニューレ装着めん羊にそれぞれ1日1回給与し、反芻胃内容物の
粒度分布の経時変化および喰下食塊と糞の粒度分布を測定した。無細切乾草1300 gを1日1回10:00
から13:00の間に採果させ、飼料給与後3、7、11、15、19、24 hに反芻胃内容物を全量取り出し、代表
サンプルを採取した。粒度分布は、Large particles（LP，≥1180μm 篩上残留分画）、Small particles
（SP，47～600μm 篩上残留分画）および可溶性分画（SOL，47μm 篥通過分画）の割合で表した。喰下
食塊のLP割合は、各乾草とも60％以上であり、5600μm 篥上残留分画割合はH1給与時がH2、H3給
与時に比べて高かった。反芻胃内容物中のLP割合は、給与後3から24 hにかけて、H1、H2、H3給与
時でそれぞれ、46→13、39→14、34→8％へと減少し、各時間におけるLP割合は、H1給与時がH2、H
3給与時に比べて高い傾向にあった。一方、SP割合は、H1、H2、H3給与時でそれぞれ、28→47、35→
62、47→88％へと増加し、各時間におけるSP割合は、H1給与時に比べてH2、H3給与時に高かった
(P<0.05)。反芻胃内容物中のSOL割合は、H1で給与後3 hの26％から給与後24 hには41％へと増
加したが、H2、H3では変動が少なく概ね25％で推移した。各乾草給与時において、反芻胃内通過が可
能な飼料粒子は常に総反芻胃内容物の50％以上を占めていた。糞のLP割合は、H1、H2、H3給与時で
それぞれ、0.7、3.7、1.0％とわずかであった。SP割合はそれぞれ48.8、53.2、70.3％とH1、H2給与時に
比べ、H3給与時で高かった。

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