トウモロコシおよびソルガムサイレージを給与した山羊における粗飼料の排糞パターンの近赤外分光分析

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Defecation Pattern in Goats Fed Maize or Sorghum Silage as Analyzed by Near-infrared Spectroscopy

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Synopsis

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Goats were fed silages at 4.9% of metabolic body weight per day. As test signal, rye hay treated with ammonia gas was fed for analyzing the continuous defecation stream at 1% of metabolic body weight together with the silage once. The feces were sampled 55 times at 3 hour intervals after feeding rye hay, and the near-infrared spectra were obtained. For data compression, correlation coefficients were calculated between the spectrum of the first sample and that of the samples collected thereafter. The change in the correlation coefficient with time was considered to show the defecation pattern of rye hay in the feces. The increase in the proportion of indigestible organic matter in the rye hay is mainly responsible for the decrease in the correlation coefficient. The correlation coefficient fluctuated with the time of sorghum silage feeding, but not with that of the maize silage feeding. In the sorghum silage, the lowest correlation coefficient was observed at 3 days after rye hay feeding. A circadian rhythmicity in the chemical composition of feces was detected by spectrum analysis. The defecation pattern of rye hay varied with the kind of silage fed together with it.

Key words : Defecation, Maize, Near-infrared, Periodicity, Ruminants, Sorghum.

Introduction

Dairy productivity was increased markedly by the advance of breeding during the last 20 years, but in addition to the knowledge of animal nutritive requirements, the knowledge of nutritional ecology is needed to avoid the metabolic disorders. Nutritional ecologists have mainly focused their attention on rumination[5,13,15,19] and the passage[10,11] and digestion rate[10,14] of the diet in the rumen. SUDWEEKS *et al.*[19] proposed roughage value index (chewing time per kilogram) to assess the coarseness of feedstuff. The dynamic model of ruminal digestion included rumination time, passage properties in the rumen and particle size[10]. The information on coarse-texture or physical form is important for estimating and forecasting digestion of feeds on the basis of their model construction. CHANDLER *et al.*[4] pointed out that the effective fiber value was a useful index in the formulation of diets for maintaining the health of ruminants. The defecation disorders often occur, even though the diet may be adequate in all known nutrients and have a sufficient coarse-texture. For example, diarrhea was often observed resulting from high intake of beet pulp, and constipation and diarrhea occurred alternately in animals feeding on the silage of sorgo type sorghum or stover silage of grain sorghum. To avoid gastrointestinal disorders, the knowledge of defecation properties is required in addition to nutrients. The defecation pattern of roughage and its effect on other feedstuff, however, remain unknown. Recently, INOUE and HAGIWARA[8] reported that fluctuation over time in the amount of feces was larger in the feeding of sorghum whole crop silage than in the feeding of maize whole crop silage and that there were differences in the periodic fluctuation between the silages. It is so difficult to investigate the defecation properties of roughage, and there have been few reports on the defecation pattern. Especially, there was no information for the relationship between defecation of hay, which was add to ration for maintaining that the gastrointestinal function is healthy, and kind of silage as a base of ration.

The objectives of this study is to clarify the defecation pattern of hay in goats feeding on maize or sorghum silage through time-series analysis by near-infrared reflectance spectroscopy, namely streaming NIR analysis.

Materials and Methods

Materials

The feedstuffs used in this experiment were whole crop silages of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moench) and rye hay treated with ammonia at the rate of 4% per air dry weight (*Secale*

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Table 1. Chemical composition and nutritive value of diets used.

	Diets		
	Maize silage	Sorghum silage	Rye hay treated with ammonia
Moisture	66.2	69.1	16.6
CP*	7.5	7.8	20.6
EE*	2.8	2.6	1.6
OCC*	63.8	45.6	31.7
OCW*	31.0	47.8	61.3
TDN*	70.2	59.7	60.9

* Dry matter basis.
CP : crude protein, EE : ether extract, OCC : organic cellular contents, OCW : organic cell wall, TDN : total digestible nutrient.

Table 2. Intake of silage and rye hay.

	Daily intake of silage (kg*)	Load per day during experiment ($g\,kg^{-1}\,BW^{-0.75}$**)	Amount of rye hay treated with ammonia (kg*)	Load of rye hay ($g\,kg^{-1}\,BW^{-0.75}$)
Goat fed sorghum silage	1.23	49	0.25	10
Goat fed maize silage	1.10	49	0.25	11

* Dry matter basis.
** $BW^{0.75}$: Metabolic body weight.

cereale L.). The chemical composition and nutritive value of the feeds are shown in Table 1. Maize variety p3358 and sorghum variety Kho 13, which was a dual purpose type and developed by the Sorghum Breeding Section of Nagano Animal Industrial Experiment Station, were used. Whole plants of maize were harvested at the yellow ripening stage and whole plants of sorghum at the dough stage, and prepared as silage. Rye hay was cut into about 3 cm pieces and treated by ammonia gas in air-tight bags. The amount of ammonia for treatment was 4% of hay on the basis of air dry weight.

The percentage of crude protein (CP) in dry matter was determined by Kjeldahl N%×6.25 : the CP content was higher in ammonia-treated rye hay than other feeds. The content of total digestible nutrient (TDN) in dry matter of silage was evaluated with 4 castrated goats. The TDN of ammonia-treated rye hay was evaluated with 12 heads of castrated goats.

The degradation pattern of the ammonia-treated rye hay in the rumen was determined by nylon bag experiment in the steer's rumen of festulated Holstein steer following the NOCEK's recommended guidelines[17]. The nylon bag porosity was 50 μm and the particle size of the feeds were 2 mm. Sample size to bag surface area was decided 9 mg cm^{-2}. Degradation test with a nylon bag was carried out in 3 replications with 3 steers. Incubation time was 0, 2, 4, 8, 48 and 72 hours. All samples were rinsed in tap water, weighed after forced-air drying at 65℃ for 48 hours and passed through 0.5 mm mesh after crushing with a centrifugal mill. The organic cell wall (OCW) contents in the dry matter was determined by enzymatic techniques[1] and kinetic mode[18] was adopted to the data for expression of the results.

Digestion trials for investigation of defecation

Two castrated goats each weighing 69 kg on average were individually fed with each silage in a cage for the digestion trial. The amount of TDN in daily ration was adjusted to be 100-150% of US National Research Council nutrient requirements in goat[23]. The load per day was 49 g per kg of metabolic body weight in each silage (Table 2). The CP content was adjusted above 12% in dry matter with urea. The goats freely drunk water during the experimental period. At the start of the experiment, rye hay as a test signal of passage fed once together with silage (Table 2).

Feces were sampled at 3 hour intervals for 7 days after a 14 day preliminary period for adaptation to the feedstuff and environment in automatic feces sampling device[8]. All samples obtained from the two goats were weighed after forced-air drying at 60℃ for 48 hours and passed through a 0.5 mm mesh after crushing with a centrifugal mill.

Streaming NIR analysis

The instrument used was InfraAlyzer 500 of BRAN +LUEBBE for scanning near-infrared reflectance (NIR) spectra of ground samples (Fig. 1).

Reflectance (Re) spectra were measured as log (1/Re) at 2 nm intervals in the wavelength range from 1,100 to 2,500 nm. In this study, rye hay as test signal of passage was fed once together with silage at the start of the experiment. Therefore, the organic chemical composition in the feces after some time lag may be affected by the indigestible organic matter (IDOM) of the rye hay. If we examine the similarity between the NIR spectra of the feces from silages with and without rye hay, the pattern of defecation derived from rye hay and its ratio to the defecation derived from silage may be detected. For data compression in this analysis, the correlation was adopted to compare the similarity between the spectra. The simple correlation function was obtained as shown in Fig. 1. $x(t_1)$ is the spectrum data at the first sampling time, t_1. The spectrum at t_1 does not contain the IDOM derived from rye hay. Therefore, $x(t_1)$ can be the reference to other spectra, $x(t_1+\tau)$. The decrease of correlation coefficient value between $x(t_1)$ and $x(t_1+\tau)$ means the increase of the contents of IDOM derived from rye hay in the feces after $3\times\tau$ hours. The time series data of correlation coefficients (corre-

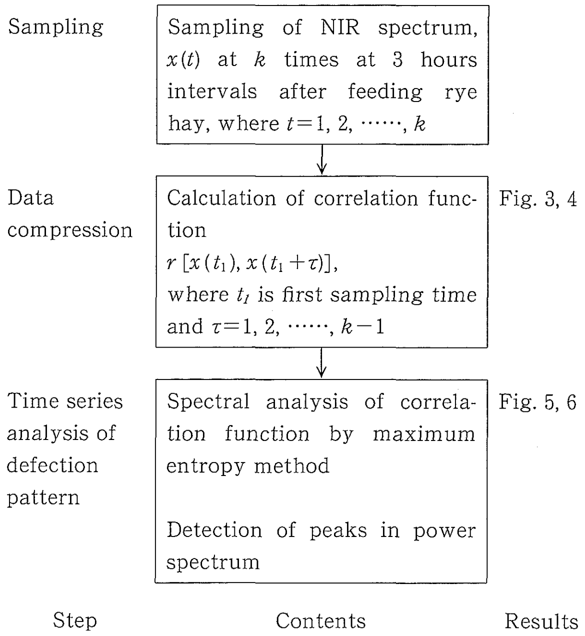

Fig. 1. Algorithm of streaming NIR analysis.

lation function) was calculated for each goat.

Spectral analysis was used to detect the periodic change in the NIR correlation function. Power spectrum densities were calculated by BURG's algorithm[3] of the maximum entropy method (MEM)[3,20]. MEM power spectrum density at a certain frequency of time (f[cycle h^{-1}]) is given as follows :

$$P(f)=\Delta t\sum_{k=-\infty}^{\infty}C(k)\,e^{-i2\pi fk\Delta t}$$

where, Δt is an interval of measurement in hours, k is the correlation lag, $C(k)$ is the correlation, and i is the integer corresponding to the measurement time. Since power spectrum analysis was applied to the amount of feces, $P(f)$ denotes the strength of periodicity in defecation with a certain frequency of time, f. In this study, Δt, the maximum value of k and the number of prediction-error filters were given values of 3, 40 and 20, respectively.

Results

Digestibility of rye hay

The OCW content was 61.3% in dry matter of rye hay treated with ammonia (Table 1). The digestibility of OCW was 73.5% in the digestion trials. Degradation of OCW in the rumen increased with incubation time (Fig. 2), and the percentage of degradation in the rumen reached the percentage of digestibility *in vivo* at 65 hours of incubation. Therefore, from the calculation ; 0.25 kg (amount of dry matter fed once) ×0.613 (OCW content in dry matter)×0.265 (1-[digestibility *in vivo* digestion trials]), the amount of IDOM from rye hay was estimated to be about 0.041 kg.

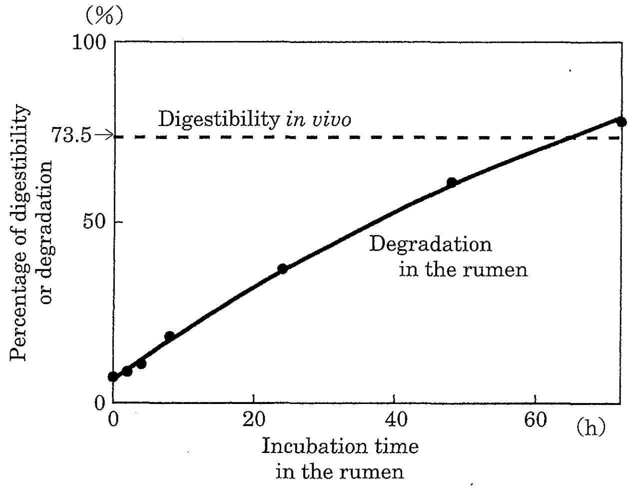

Fig. 2. Characteristics of OCW digestion of rye hay treated with ammonia gas.

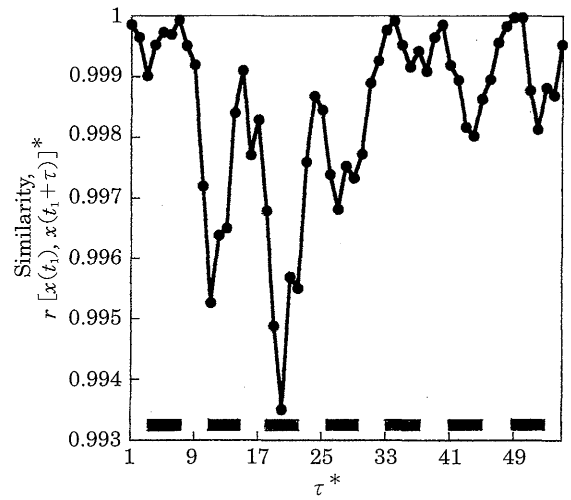

Fig. 3. Similarity of NIR spectra in defecation of goat fed sorghum silage.
* See Fig. 1.
▬ Night.

Defecation pattern of rye hay detected by streaming NIR analysis

The defecation pattern of rye hay was calculated by algorithm in Fig. 1.

The peak of decrease in correlation was detected at about 60 hours (τ=20) after feeding on rye for sorghum silage feeding (Fig. 3). With sorghum silage feeding, the daily peak of the decrease was observed at night (8 to 11 p.m.). With maize silage feeding by contrast with sorghum, no obvious peak was observed (Fig. 4).

To confirm the periodicity in defecation derived from rye hay, I analyzed the correlation function for the similarity of NIR spectra of defecated IDOM by MEM spectral analysis. An obvious peak of power density $P(f)$ was detected in the power spectral diagram in sorghum silage feeding (Fig. 5). The fre-

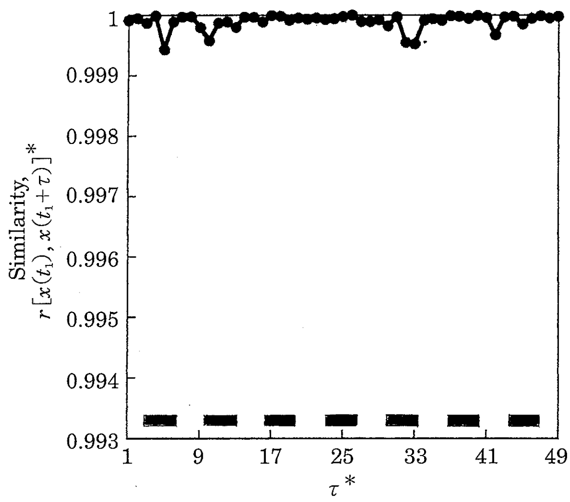

Fig. 4. Similarity of NIR spectra in defecation of goat fed maize silage.
* See Fig. 1.
▬ Night.

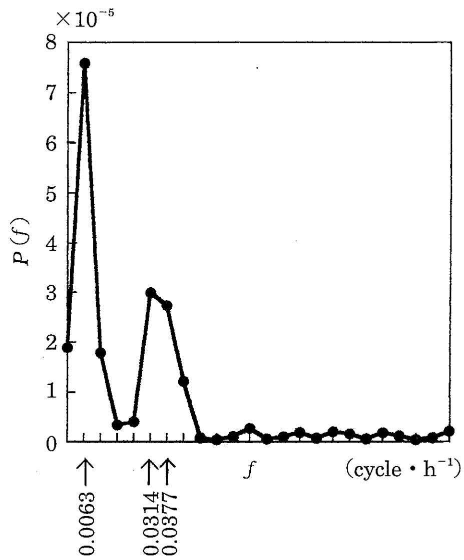

Fig. 5. NEM power spectrum from the correlation function in soghum (Fig. 3).

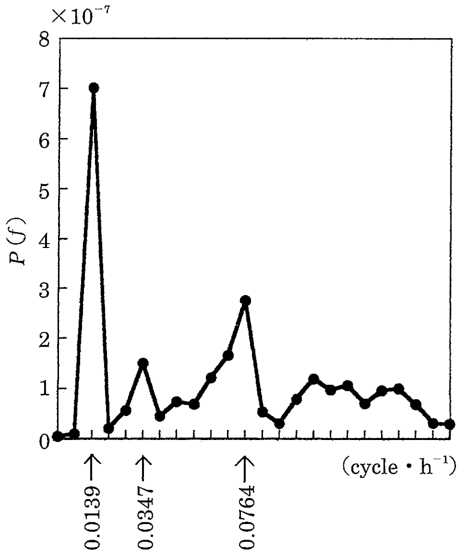

Fig. 6. NEM power spectrum from the correlation function in maize (Fig. 4).

quency (f) was 0.0063, namely 159 hours per cycle. Furthermore, a peak with lower power density was also detected at a higher frequency from 0.0314 (32 h per cycle) to 0.0377 (27 h per cycle).

On the other hand, in maize silage feeding (Fig. 6), 3 peaks were observed in power spectral diagrams, but the power density was extremely lower than that in sorghum silage feeding. The frequency (f) was 0.0139, 0.0764 and 0.0347, namely 72, 13 and 29 h per cycle, respectively.

Discussion

The streaming properties of the feed through the gastrointestinal tract can be clarified by detecting and analyzing the fluctuation of the chemical composition in feces. The chemical composition of organic matter in the feces will fluctuate when ruminants feed on hay once. The hay feeding once is considered to be a pulse signal in streaming analysis[12]. The key of the technique may be in the detection of a slight change of the chemical composition.

Chemometrics after NIR analysis are variables for analysis of organic matter in the feces[7], therefore the procedures was adopted in this study. Many reports revealed that the gastrointestinal transit time is about from 40 to 90 hours[2,17]. In this study, an obvious peak of defecation was observed at about 60 hours after feeding rye hay with sorghum silage feeding. Furthermore, in the case of digestion trials for only rye hay, the transit time of the OCW, which was estimated by the incubation time at the point of intersection between *in vivo* digestibility and *in situ* degradability in the rumen calculated from kinetic model, was about 65 hours (Fig. 2). From the results, the detection of the peak in the streaming NIR analysis for the defecation of rye hay as a test signal (impulse) suggested that the method may be also useful for measurement of the transit time, an important parameter in nutritional ecology[21].

The indigestible materials such as heavy metals[6,9] have been used commonly as a transit marker of feedstuff. However, the results obtained by labeling the feedstuff with these markers are variable[9], the marker may adversely influence the animal and moreover the analysis is expensive. Therefore, the development of a more suitable method is awaited. The streaming NIR analysis by using the feedstuff itself as a marker may be useful in this respect. In this study, the defecation patterns of the feedstuff

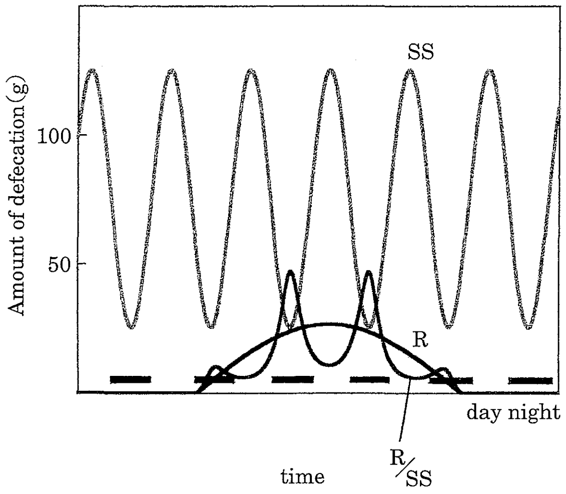

Fig. 7. Schematic drawing of roughage defecation under sorghum silage feeding.
SS : sorghum silage, R : rye hay, R/SS : defecation ratio of rye hay to sorghum silage.

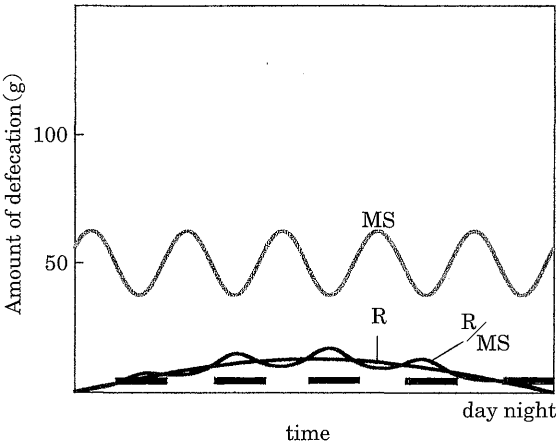

Fig. 8. Schematic drawing of roughage defecation under maize silage feeding.
MS : maize silage, R : rye hay, R/MS : defecation ratio of rye hay to maize silage.

with and without signal hay were compared. For accurate estimation of the amount of feces, a new algorithm needs to be developed in future.

Inoue and Hagiwara[8] reported that the amount of feces on a dry matter basis was larger in the daytime than at night showing and an obvious short-term fluctuation like a semidian rhythm (12 hours per cycle) and a circadian rhythm under sorghum silage feeding. In sorghum silage feeding, in this study, I estimated that the proportion of feces derived from rye hay in the whole feces was higher at night than in the daytime and there was periodic fluctuation in the concentration (32 h per cycle) (Figs. 3, 5). On the other hand, under feeding maize silage, the amount of feces on a dry matter basis was also larger in the daytime than at night[8] and there were small peaks in correlation function (Fig. 4), power density of periodic fluctuation being lower than that under sorghum silage feeding.

Consequently, I concluded that there was a difference between the fluctuation of the concentration of IDOM derived from rye hay in the feces and that of IDOM from silages, and the time course of the fluctuation of the concentration varied with the kind of silage.

The simpler cosinor model was constructed to analyze the phenomena. The model has 3 assumptions : (1) the defecation pattern of dry matter varied with the kind of silage, (2) the duration of defecation originated by rye hay was varies with the kind of silage, in other words, there is interaction among defecation of roughage, and (3) the amount of whole feces can be integrated from feces derived from each feedstuff. The schematic drawings are shown in Figs. 7 and 8.

The cosinor curves in both figures were simplified and drawn on the assumption that the magnitude of fluctuation was larger under sorghum silage feeding than under maize silage feeding[8]. The pattern of defecation derived from rye hay over time has one peak after feeding and as shown in the figures. The amount of feces derived from each feedstuff could be separated. The amount of IDOM derived from rye hay in feces (R) may be higher at night than in the daytime because the amount of feces derived from sorghum (SS) decreased at night. The ratio (R/SS in Fig. 7) may be related to the proportion of R in the whole feces, and similarity of correlation function (Figs. 3 and 4) as follows ;

$$r[x(t_1),\ x(t_1+\tau)] \fallingdotseq f(\mathrm{R/SS}).$$

This hypothesis fully explains the results in Fig. 3.

Under maize silage feeding, the amount of daily defecation derived from maize silage (MS) was smaller than under sorghum silage (SS) feeding, because the maize silage had higher TDN content and smaller amount of OCW than the sorghum silage. If the amount of feces derived from rye hay and the defecation pattern over time were equal to R in Fig. 7, the ratio of amount of IDOM derived from rye hay to that derived from maize silage (R/MS) would be larger than R/SS. In this experiment, however, correlation function fluctuated only slightly over time (Fig. 4).

The pattern of defecation of rye hay (R) varied with the kind of silage, namely, (1) the range of defecation time is wider, and/or (2) the digestibility is higher for maize silage feeding than for sorghum silage feeding (Fig. 8). This hypothesis explains why the fluctuation of defecation derived from rye hay in maize silage feeding was lower than that under sorghum silage feeding.

Why was the digestibility of rye hay under maize silage feeding higher than under sorghum silage? In the present experiment, daily load of silage dry matter was 49 g per kg of metabolic body weight in goat (Table 2), and the amount of intake of both silages was lower than the upper limit of intake[22]. However, the load of fiber per day under maize silage feeding was lower than that under sorghum silage feeding. Therefore, the amount of enzymes per fiber in gastrointestinal tract might be higher under feeding maize silage feeding. Consequently, the organic matter of rye hay under maize silage feeding might be more easily degraded by microorganisms.

The periodic fluctuation of defecation under maize silage feeding was smaller than under sorghum silage feeding. In this experiment, the grain contents in maize silage was also higher than that in sorghum silage, and fiber contents in maize silage was 65% of sorghum silage. When the intake of effective fiber[4] was lower, ruminants might tend to hold the fiber for a longer period in the gastrointestinal tract and consequently maintain stable fermentation. The adaptation to these diets might result in the spreading of the time of defecation derived from rye hay under maize silage feeding.

The potential digestibility of the ammonia-treated rye hay seemed to be high from the degradation data in the rumen (Fig. 2). The degradation rate did not reach the plateau even when the incubation time was increased to 72 hours. Therefore, the longer the fiber of rye hay stays in gastrointestinal tract, the higher the digestibility and the lower the daily amount of feces derived from rye hay (R in Fig. 8) and R/MS.

The important information necessary to prevent the digestive disorders would be not only rumination, passage and digestion rate but also defecation of the effective fiber and the interaction with roughage. These relationships are poorly understood and need additional intensive examination.

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* : In Japanese.
** : In Japanese with English summary.

要　　旨

井上直人 (2001) : トウモロコシおよびソルガムサイレージを給与した山羊における粗飼料の排糞パターンの近赤外分光分析. 日草誌 **47**, 471–477. 信州大学　農学部　食料生産科学科 (399-4598 長野県上伊那郡南箕輪村 8304)

代謝体重当たり4.9%の乾物に相当するトウモロコシやソルガムサイレージを与えて飼養された山羊に代謝体重当たり1%の乾物に相当する4%アンモニア処理ライムギを1回だけ摂取させ，以後排泄されてくるライムギ由来の有機物を近赤外分光分析で検出した。分析用の糞は3時間おきに55回採集して乾燥・粉砕した。近赤外スペクトルは1,100 nm から 2,500 nm まで 2 nm 間隔で測定された。情報圧縮のために，試験開始直後のスペクトルとそれ以後のスペクトルの類似度を相関係数で求めた（相関関数)。相関関数はソルガムサイレージでは大きく変化したが，トウモロコシサイレージでは変化が見られなかった。ソルガムサイレージでは約3日目に相関係数が最も低下した。相関関数に対して MEM スペクトル解析すると，排泄物の化学成分の変動には日周期があることがわかった。一方，トウモロコシサイレージではその変動は微弱であった。粗飼料の排泄パターンはサイレージの種類によって大きな差があると考えられた。

キーワード : 近赤外, 周期性, ソルガム, トウモロコシ, 排糞, 反すう動物.