ビッグベール乾草調製時におけるヒートダメージについて

誌名	日本草地学会誌
ISSN	04475933
著者	前田, 良之 岡本, 明治 吉田, 則人
巻/号	34巻3号
掲載ページ	p. 193-201
発行年月	1988年10月

J. Japan. Grassl. Sci., 34 (3) : 193-201 (1988)

Heat Damage in Hay-making of Big Round Bale

Yoshiyuki MAEDA*, Meiji OKAMOTO** and Norihito YOSHIDA**

Synopsis

MAEDA, Y., M. OKAMOTO and N. YOSHIDA (1987) Heat damage in hay-making of big round bale. *J. Japan. Grassl. Sci.,* **34**, 193-201.

Big round bales were prepared at two levels of moisture contents (37% and 24%) in order to investigate their heat damage. The central part of the big round bale prepared at 37% moisture content, which showed temperature rise of reaching up to 56°C, was assigned to the high temperature section. The circumference of the high temperature section was assigned to the middle temperature section. The low temperature section was decided to be the bale prepared at 24% moisture content, which showed the temperature of 31°C at 4th day after baling. The experimental results were as follows.

1. Contents of ADF, NDF, hemicellulose, cellulose and lignin were the highest at the middle temperature section, and were the lowest at the high temperature section. Values of ADIN/T-N and NDIN/T-N were the highest at the high temperature section, showing 15.0% and 51.0% as compared to 14.4% and 33.1% at the middle temperature section and 11.6% and 19.4% at the low temperature section, respectively.

2. At the middle and high temperature sections, crude protein digestibility was lower, but digestibilities of dry matter, organic matter, ADF, NDF, hemicellulose, cellulose and energy were higher as compared to those at the low temperature section. Crude fat digestibility was the highest at the high temperature section. Contents of TDN and DE were the lowest at the low temperature section, but content of DCP was the highest at the low temperature section.

3. Ammonia-N concentration in the rumen of the sheep fed on hay of the high temperature section kept its level almost always lower than those of the other two sections. Total VFAs concentration in the rumen of the sheep fed on hay of the high temperature section was almost always higher than those of the other two sections.

4. Faecal N output became larger and urinary N excretion smaller when the sheep were fed hay of the higher temperature sections in the bales. Though retained N was the largest at the high temperature section, the difference among the sections was not statistically significant.

Key words : Big round bale, Digestibility, Heat damage.

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* Fuji Zootechnical Station, Tokyo University of Agriculture, Fujinomiya-shi 418-02
** Laboratory of Grassland Utilization, Obihiro University of Agriculture and Veterinary Medicine, Obihiro 080

Introduction

Big round bale is being watched from viewpoints of such merits as the curtailment of consumption of twine and the reduction of labor in transport-stock operations. In addition, it has recently been utilized as a roll bale silage[13]. With those things for a background, there may be much chance to make the big round bale. When the big round bale is prepared as hay, material should be baled at less than 20% of moisture content. It is reported that when the moisture content is more than the adequate level, many troubles like heat production, carbonization and fire during stock occur[10]. Those phenomena are recognized as heat damage[16].

In spite of a lot of examples for heat damage, there are few reports that actually showed changes in temperature of the inside of the big round bale and discussed the relationships among heat production, chemical composition and utilization for ruminants.[17]

In this study, heat damage was clarified in case of preparing hay of big round bale, and changes in temperature, chemical composition and availability for sheep were discussed.

Materials and Methods

1. Materials

First cutting orchardgrass was dried in the field to make big round bales. The bales were prepared when moisture content became about 30% and 20%, being regarded as high and low moisture bales, respectively. Those bales were made in tripricate. The changes in temperature

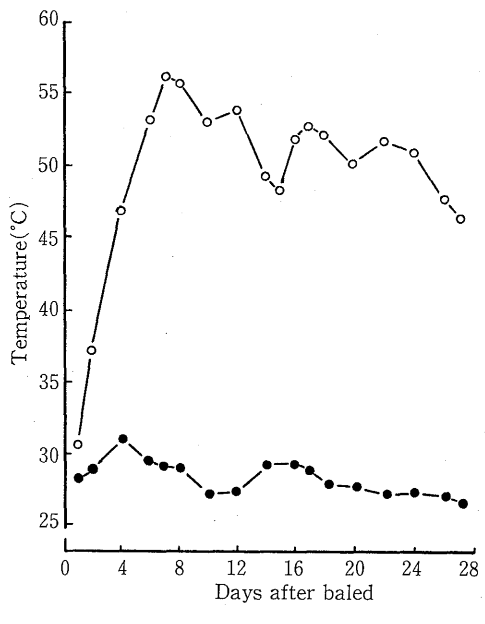

Fig. 1. Changes in temperature in big bales.
(—○—) : 36.6% moisture content,
(—●—) : 23.9% moisture content.

of the inside of bales were measured by the thermoelectric couples. As shown in **Fig. 1**, the temperature in the high moisture bales went up immediately after baling and reached up to 56°C at 7th day after baling. In the low moisture bales, the temperature reached only 31°C at 4th day after baling. According to the result of changes in temperature, three sections for bales were defined as follows. The central and brown part of high moisture bale was assigned to high temperature section. Middle temperature section was non-brown part of high moisture bales. Low temperature section was decided as low moisture bales. After 30 days from baling, those bales were re-baled to compact bales at each section. Moisture content, diameter, volume, weight and density of bales were shown in **Table 1**.

2. Digestion and nitrogen balance test

The experimental six sheep including two rumen-fistulated sheep, weighing 46-61 kg, were kept in metabolism cages throughout the experimental period. 7-day sampling period was preceded by 7-day preliminary period. Each sheep was fed with about 1.5% dry matter of diet per body weight per day, and water and salt licks containing trace minerals were accessible at all time. Digestibility test and nitrogen balance test were carried out by means of total collection method.

3. Investigation of rumen content

Rumen liquor was taken out through the rumen fistula during 3 days after sampling period; and pH value, concentrations of ammonia-N and VFAs were measured. Feeding condition during the measurement was the same as that in the sampling period.

4. Chemical analyses

Moisture, crude protein and crude fat were determined by AOAC procedures[1]. NDF (neutral detergent fiber), ADF (acid detergent fiber), hemicellulose, cellulose, lignin and silica were estimated according to the method of National Institute of Animal Industry[12], but sodium sulfite was not added in the process of determining NDF. ADIN (acid detergent insoluble nitrogen) and NDIN (neutral detergent insoluble nitrogen) were determined as nitrogen contents in ADF and NDF, respectively[6]. Calory was measured by bomb-calory meter. Nitrogen in urine was determined by micro-Kjeldahl technique[1]. Measurement of pH was carried out with a glass electrode pH meter. Ammonia-N (NH_3-N) was measured by micro-diffusion method[11], and total volatile fatty acids by gas-liquid chromatography[5].

Table 1. Physical form of big bales prepared under high and low moisture contents.

Treatment	Moisture content (%)	Diameter (m)	Width (m)	Volume (m^3)	Weight (kg)	Density (kg/m^3)
High moisture	36.6	1.90	1.60	4.5	520	114.6
	38.1	1.70	1.60	3.6	530	145.9
	35.1	1.65	1.60	3.4	620	181.1
Low moisture	23.9	1.60	1.55	3.1	420	134.8
	22.3	1.54	1.55	2.9	410	142.0
	25.5	1.66	1.55	3.4	460	137.1

Results

The chemical composition of the materials were shown in **Table 2.** The contents of ADF, NDF, hemicellulose, cellulose, lignin and silica in the original grass were lower than those in the big-baled hay. In the big-baled hay, crude protein content showed the highest value of 9.7 % at the low temperature section, as compared to 8.7% and 9.2% at the middle and high temperature sections, respectively. Crude fat content showed the highest value at the high temperature section. Contents of ADF, NDF, hemicellulose, cellulose and lignin were the highest at the middle temperature section. Contents of ADIN, ADIN/T-N, NDIN and NDIN/T-N in the big-baled hay showed the highest values at the high temperature section, and the lowest at the low temperature section.

The digestibility and digestible nutrient content of the sections were shown in **Table 3.** At the middle and high temperature sections, crude protein digestibilities was lower, but digestibilities of dry matter, organic matter, ADF, NDF, hemicellulose, cellulose and energy were higher as compared to those of the low temperature section. Crude fat digestibility was the highest at the high temperature section. TDN and DE contents were the lowest at the low temperature section. DCP content was the highest at the low temperature section.

The changes in pH values in the rumen fluid were shown in **Fig. 2.** The values in all treatments decreased immediately during the first 3-4 hours after feeding, but increased

Table 2. Chemical composition of materials

Composition (%)	Original grass	Big-baled hay		
		Temperature in bale		
		Low	Middle	High
Dry matter	13.9	87.5	86.7	86.2
	% of dry matter			
Organic matter	91.9	90.9	90.8	91.0
Crude protein	10.1	9.7	8.7	9.2
Crude fat	2.6	2.3	2.2	2.7
ADF[a]	38.2	43.8	48.6	42.7
NDF[b]	62.8	77.6	82.9	74.9
Hemicellulose	24.6	33.8	34.3	32.2
Cellulose	33.6	37.0	41.5	36.4
Lignin	3.1	5.0	5.3	4.3
Silica	1.5	1.8	1.8	2.0
ADIN[c]	0.17	0.18	0.20	0.22
ADIN/T-N	10.5	11.6	14.4	15.0
NDIN[d]	0.45	0.30	0.46	0.75
NDIN/T-N	27.8	19.4	33.1	51.0
Energy (Kcal/g)	4.69	4.67	4.71	4.66

a) Acid detergent fiber.
b) Neutral detergent fiber.
c) Acid detergent insoluble nitrogen.
d) Neutral detergent insoluble nitrogen.

Table 3. Digestibility coefficients and nutrient contents of materials

	Temperature in bale		
	Low	Middle	High
Digestibility (%)			
Dry matter	55.0±1.9[b] *	63.0±0.87[a]	62.3±0.46[a]
Organic matter	56.6±1.7[b]	64.9±0.87[a]	63.9±0.58[a]
Crude protein	46.7±1.9[b]	42.6±1.1[a]	40.0±0.86[a]
Crude fat	40.9±2.8[b]	43.9±2.3[b]	54.8±1.0[a]
ADF	65.1±2.1[b]	75.7±1.1[a]	73.3±1.1[a]
NDF	59.0±2.5[b]	73.5±1.2[a]	69.8±0.75[a]
Hemicellulose	71.6±3.1	78.7±1.4	77.9±2.1
Cellulose	70.6±2.2[b]	83.8±1.1[a]	80.7±0.8[a]
Energy	54.7±1.7[b]	63.1±0.90[a]	61.5±0.46[a]
Nutritive value (% of dry matter)			
TDN	50.5±1.1[b]	57.9±0.80[a]	57.0±0.35[a]
DCP	4.5±0.29	3.7±0.17	3.7±0.17
DE (Kcal/g)	2.58±0.09	2.96±0.04	2.93±0.02

* Values are expressed as mean±standard error.
a-b) Values in the same line with different superscripts are significantly different ($P<0.05$).

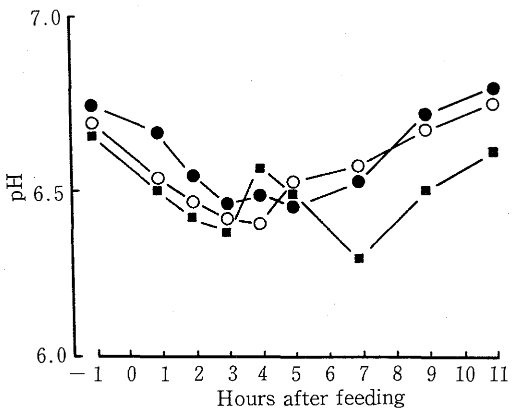

Fig. 2. Changes in pH.
(—○—) : High temperature section, (—●—) : Middle temperature section, (—■—) : Low temperature section.

thereafter. The pH value tended to keep lower at the low temperature section than at the middle and high, and this trend became particularly clear after 5 hours after feeding. The changes in NH_3-N values in the rumen were shown in **Fig. 3.** The values in all treatments elevated remarkably just after feeding, and reached to the highest value at 1–2 hours after feeding. Thereafter, the value decreased rapidly. The value at the high temperature section showed 6–21 mg/100 ml, being always lower than 10–25 mg/100 ml at the middle and low temperature sections. The changes in total VFAs concentration in the rumen were shown in **Fig. 4.** The values in all treatments reached to the highest value at 2–3 hours after feeding,

Table 4. Nitrogen balance of sheep

	Temperature in bale		
	Low	Middle	High
N intake (g/day)	13.8±1.04*	12.9±0.69	13.6±0.69
N in feces (g/day)	7.3±0.40	7.4±0.29	8.2±0.29
N digested (g/day)	6.5±0.81	5.5±0.52	5.5±0.46
N in urine (g/day)	7.3±0.52[a]	5.6±0.52[b]	5.1±0.29[b]
N retained (g/day)	−0.8±1.15	−0.1±0.69	0.4±0.52
as % of intake	−7.3±8.60	−1.3±5.14	2.5±3.70
as % of digested	−12.2±24.4	−0.1±1.44	5.2±9.24

* Values are expressed as mean±standard error.
a-b) Values in the same line with different superscripts are significantly different ($P<0.05$).

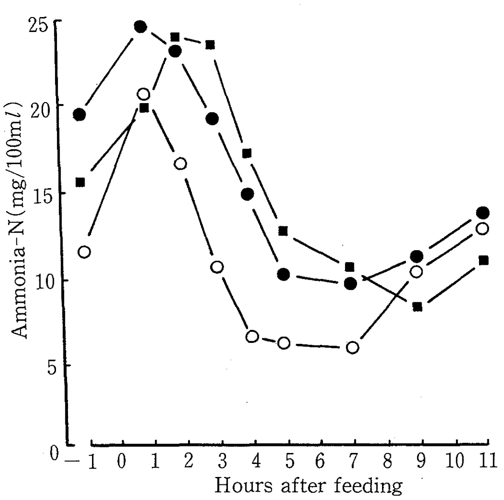

Fig. 3. Changes in concentration of ammonia-nitrogen.
(—○—) : High temperature section,
(—●—) : Middle temperature section,
(—■—) : Low temperature section.

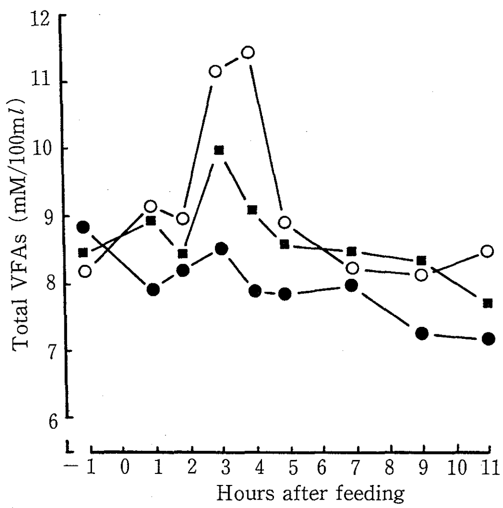

Fig. 4. Changes in concentration of total volatile fatty acids.
(—○—) : High temperature section,
(—●—) : Middle temperature section,
(—■—) : Low temperature section.

and those values ranged from 7 to 12 mmol/100 m*l*. The highest concentration of VFAs was observed at the high temperature section.

Nitrogen balance in sheep was shown in **Table 4.** Faecal nitrogen output was 8.2 g/day at the high temperature section, 7.4 g/day at the middle and 7.3 g/day at the low. Digested nitrogen were 5.5 g/day at the high and middle temperature sections, and this value tended to be lower than that at the low temperature section (6.5 g/day). On the other hand, urinary nitrogen excretion was the highest at the low temperature section (7.3 g/day), as compared to 5.6 g/day at the middle and 5.1 g/day at the high. As a result, retained nitrogen tended to be larger at the high temperature section than at the low and middle temperature sections.

Discussion

With regard to the cause of heat production in the stocked big round bales, the moisture content of bales is generally recognized[10]. When the bale is stored at high moisture content (over 20%), heat production is taken place by aerobic deterioration[14].

In this experiment, because of bad weather, the moisture content of the bales could not be adjusted to the level lower than 20%. As a result, the bales of 37% moisture content were established as high moisture bales and those of 24% moisture content as low moisture bales. In case of 37% moisture content, the temperature of the inside of bales raised rapidly above 50°C. Meanwhile, in case of 24% moisture content, the temperature raised to 31°C at 4th day after baling, thereafter, little change was found during 28 days after baling.

With regard to the chemical composition of each temperature section, the values of ADIN, NDIN, ADIN/T-N and NDIN/T-N became higher in the order of the low, middle and high temperature sections. The contents of NDF and ADF were decreased in the order of the middle, low and high temperature sections.

When feedstuffs are affected by high temperature above 50°C, it is known that the digestibility of protein in feed decreased, showing the increase of value of ADIN/T-N as the best indicator of indigestible nitrogen[4]. This phenomenon is called heat damage. The degree of heat damage could be judged by the value of ADIN/T-N. Therefore, in this experiment, it was considered that heat damage occurred in the high temperature section. As to the effects of heating on the composition of fiber, VAN SOEST *et al.*[15] and YU YU *et al.*[17] reported that ADF and NDF contents were increased by heating. However, the results of this study, showing the lowest values at the high temperature section, did not support their reports. The reason for the disagreement was not clear.

The crude protein digestibility was lower at the middle and high temperature sections than at the low temperature section. In general, it is well known that the most sensitive component affected by heating is protein. Many researchers reported on the declines in protein solubility and digestibility caused by heating[9,18]. In this experiment, ammonia-N concentration in the rumen showed the lowest value at the high temperature section. It is considered that the decline in solubility of feed protein caused decrease in concentration of ammonia-N in the rumen, moreover those declines are assumed to be the cause of decrease in protein digestibility.

The ADF and NDF digestibilities were higher at the middle and high temperature sections than at the low temperature section. In general, the fiber digestion almost depends on the ruminal fermentation. The factor which controls the fermentation is considered to be the sources of energy and nitrogen from a viewpoint of feeding[2]. When ruminants are fed on hay, the condition of rumen is usually stable. In this experiment, total VFAs concentration was the highest at the high temperature section. This indicates that the amount of carbohydrates decomposed in the rumen is large. Thus, it is presumed that the digestibilities of NDF and ADF showed higher values at the high temperature section than at the low. With regard to the digestibilities of NDF and ADF affected by heating, MATSUOKA *et al.*[7] reported that ADF digestibility was higher for the silages deteriorated due to temperature rise (about 50°C) than for the control silage without temperature rise. On the contrary, FURUKAWA *et al.*[3] reported that the brown silages showed lower digestibilities of NDF and ADF as compared to the normal silages. Thus, digestibility of fiber affected by heating does not show the definite tendency.

In nitrogen balance trial, faecal nitrogen output became larger and urinary nitrogen excretion smaller as the temperature in the bales became higher. However, there was no significant difference in retained nitrogen among the temperature sections. The effect of heating on the retained nitrogen was not clear.

As a result of this study, when prewilting in hay-making of big round bales was not adequately done, it was confirmed that heat production occurred and heat damage was actually shown. On the other hand, though digestibilities of NDF and ADF showed higher values at the high temperature section than at the low, the results must be further discussed by investigating the other examples.

Acknowledgements

The authors wish to thank Dr. Toyokazu YAMADA, professor at Tokyo University of Agriculture, for his valuable comments on the manuscript.

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(Received on November 9, 1987)

ビッグベール乾草調製時におけるヒートダメージについて

前田良之*・岡本明治**・吉田則人**

* 東京農業大学富士畜産農場（418-02 静岡県富士宮市麓 422）
** 帯広畜産大学草地利用学研究室（080 北海道帯広市稲田町）

要　　旨

ビッグベール調製時におけるヒートダメージを，発熱温度，成分組成および羊による利用性との関連から検討するために，水分含量 37% および 24% で梱包したビッグベールを調製して試験を行った。水分含量 37% のビッグベールの温度は梱包後 7 日目に 56℃ に達し，約 20 日間 50℃ 以上の高温を示していた。一方，水分含量 24% のビッグベールは梱包後 4 日目に 31℃ に達したが，その後低下し，27℃ 前後の温度であった。そこで，水分含量 37% で梱包したビッグベールの中心付近を高温区，その周辺の非褐変部を中温区，また水分含量 24% で梱包したビッグベールを低温区として設定した。

1.　ADF, NDF, ヘミセルロース，セルロースおよびリグニン含量は，中温区で最も高く，逆に高温区で最も低い値であった。一方，ADIN/T-N および NDIN/T-N の値は，高温区で最も高く，最も低い低温区の 11.6% および 19.4% に対してそれぞれ 15.0% および 51.0% であった。

2.　発熱の影響をうけた中，高温区では粗蛋白質の消化率は低かったが，乾物，有機物，ADF, NDF，ヘミセルロース，セルロースおよびエネルギーの消化率は低温区にくらべて高い値であった。粗脂肪の消化率は高温区で最も高かった。TDN および DE 含量は中，高温区で高く，DCP 含量は低温区で高かった。

3.　ルーメン内のアンモニア態窒素濃度は，高温区が中，低温区にくらべて低位で推移した。また VFA 濃度は高温区が中，低温区にくらべて高く推移した。

4.　窒素出納試験の結果，発熱温度が高くなるにつれて糞中排泄窒素は増加し，尿中排泄窒素は減少した。窒素蓄積率は高温区で高かったが，有意な差ではなかった。

キーワード： ビッグベール，消化率，ヒートダメージ．

日草誌 **34** (3)：193～201 (1988)