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Safe Ammonia Treatment System of Cereal Straws for Ruminant Feeding

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Abstract

An ammonia treatment system for cereal straws has been recently developed in Japan. The new method is based on a contractor system and is referred to as the "HOKUNOU-S" system. Ammoniation can be used for all types of silos, including, stack, bag, tube and bunker silos as well as wrapped bales. In addition, this technique is suitable for use where a safe, economical, labor-saving treatment with ammonia can be applied. The injection system consists of a large-sized high-pressure vessel, a volume and pressure regulator, lead hose, an injection pipe and nozzle; the durability of this equipment and the safety of its handling comply with Japanese industrial standards. For one treatment, normally 8 kg of ammonia is injected into a round bale 1.2 m in diameter within 1-2 min, About 10 t or 40 round bales of cercal straw can be treated by a contractor within 1 h. By treating rice straw with ammonia, the TDN content of rice straw increased from 40 to 60%. As a result, treated rice straw was similar to good quality grass hay while treated barley and wheat straws were similar to grass hay harvested at a slightly later stage. An adequate level of breeding efficiency in yearly calving was obtained in the 3-year reproduction test using a total of 96 breeding cattle. The cost varied with the supply and demand of straw, the length of the actual working time of the wrapping machine, and field conditions (wet conditions cause an increase in time and therefore an increase in harvesting expenses).

Discipline: Animal industry
Additional key words: silage, animal nutrition, hyperexcitability in cattle

Introduction

Feeding value, palatability, and digestibility of low-quality cereal straws can be remarkably improved by treatment of the straw with ammonia[7]. Ammoniation of straw has thus contributed to a considerable increase in livestock production in many countries. A fully automated system of ammoniation is already being employed in some European countries. However, a method for ammoniating crop residues has only been partly adopted in Japan due to the difficulty in handling ammonia and farmers' collection of cereal straw. Furthermore, in Japan, the storage, transportation, handling and application of ammonia are more strictly regulated than in other countries. Use of ammonia is restricted by the following regulations: the Poisonous and Deleterious Substance Control Law, the High Pressure Gas Control Law, the Fire Service Law, the Industrial Safety and Health Law, and the Ordinance on the Prevention of Hazards due to Specified Chemical Substances. To promote widespread production and the use of cereal straw for feed, it is necessary to develop a safe, low-cost ammonia process as well as a system for supplying and using ammonia safely. Such a treatment system has been recently developed in Japan. The new method based on a contractor system is referred to as the "HOKUNOU-S" system[3].

Description of the contractor system "HOKUNOU-S"

The operation of this new system consists of the following 3 functions: collection of cereal straw, wrapping of the straw with plastic stretch film, and ammonia injection. A specially trained and certified contractor injects liquid ammonia into wrapped round bales through a perforated stainless steel pipe. As illustrated in Fig. 1, the contractors are responsible for dealing with the treatment while the farmers are required to bale, collect, and wrap the straw to be treated. Ammoniation can be used for all types of silos, including stack, bag, tube and bunker silos,

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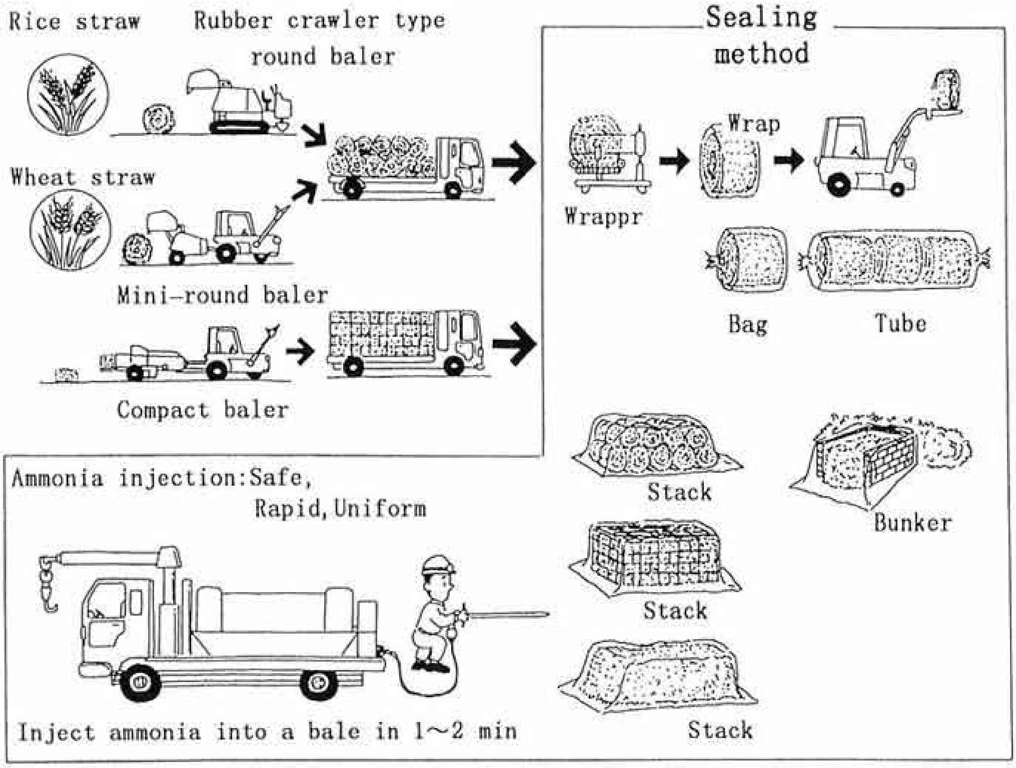

Fig. 1. Illustration of "HOKUNOU-S", a new contractor system

as well as wrapped bales. In addition, this technique is suitable for use where a safe, economical, labor-saving treatment with ammonia can be applied and where the results of its effectiveness can be confirmed (Fig. 2). For outside storage, round bales wrapped with plastic stretch film allow for better treatment and preservation. There is a minimum risk of waste compared with that of stack and bunker silos. If the moisture content is high, the quality of straw ammoniated in stack or bunker silos is often reduced soon after opening.

Fig. 2. Rapid and safe injection of ammonia

1) Rapid and efficient operation of ammonia injection

The injection system consists of a large-sized high pressure vessel, a volume and pressure regulator, lead hose, an injection pipe and nozzle; the durability and safety of handling of this equipment comply with the Japanese industrial standards. Ammonia is injected through a perforated stainless steel pipe, the sharpened conical head of which is easily inserted into wrapped bales of straw. The pipe is perforated with a number of holes, 2–3 mm apart, along its length for efficient and faster injection of liquid ammonia, which results in the thorough volatilization of the remaining ammonia, as indicated by structural tests. A variable orifice meter controls the flow rate of liquid ammonia to the bale. However, other factors affect the flow rate of ammonia, such as the ambient temperature and the pressure of ammonia in the vessel. For one treatment, normally 8 kg of ammonia is injected to a round bale 1.2 m in diameter within 1–2 min. About 10 t or 40 round bales of cereal straw can be treated by a contractor within 1 h.

2) New plastic stretch film and air-tightness

Cereal straw, air-dried to less than 30% of its original moisture content, is collected and wrapped with a newly introduced plastic stretch film. This film was developed to improve various physical properties including the ability to stretch, plasticity, clinging ability and

Fig. 3 Wrapping of cereal straw with plastic stretch film

durability. All of these are combined to ensure a complete airtight seal for the prevention of mold growth and better preservation over longer periods of time, even when ammoniation is delayed (Fig. 3). A rudimentary method of ammoniation was used to inhibit further mold growth in grass hay and cereal straw, particularly when they became wet due to rain. However, such wet materials must not be injected with ammonia, due to the possible formation of toxic substances. Due to the security issues relating to the safety of livestock feed and public food supply, there is a growing awareness of the potential problems associated with ammoniation of crop residues with excessively high moisture. These issues will be discussed later in this report.

3) Appropriate amount of ammonia injected

Based on a number of experiments, the quality of treated straw can be improved when the amount of ammonia added increases. An amount of ammonia ranging from 2.5 to 3.5%, based on the dry matter of the straw, can be justified for the cost. Since in straw containing more than 30% moisture, a reduction in forage quality and the occurrence of toxic products are likely to occur, emphasis should be placed to determine the maximum amount of ammonia that can be safely administered. Four percent ammonia, based on the dry matter content, may be recommended as the upper limit. This amount will result in high performance in terms of cost and will also enable to avoid the risk of toxicity problems in livestock, e.g., hyperexcitability. As the concentration of ammonia is closely related to a satisfactory reaction with the straw, it is preferable to hire trained contractors than using farmers' more rudimentary methods to ensure that an accurate amount of ammonia is injected.

Table 1. Distribution of ammonia injected into feedstuffs

Type of silo	Bag silo			Wrap silo
Days after injection	14	28	56	56
			%	
Straw-absorbed NH3	70	89	84	109
Straw-bound NH3	20	34	35	40
Permeated NH3	0.2	0.3	0.4	0.8
Released NH3	30	10	16	–9

Cereal straw was treated with 3% ammonia based on dry matter weight.

4) Distribution of ammonia injected into straw

When ammonia is injected into the straw and absorbed, it binds to the fiber. Although the concentration of ammonia during dissipation remained at about 3.9% in a bag silo and 6.1% in a wrap silo just after injection, it drastically decreased to less than 1.0% after about 20 days and 0.78 and 0.82% remained approximately 103 days later, respectively. It was also observed that treatment with 1% ammonia always resulted in a lower level of permeation of ammonia than treatment with 3%, as evidenced by the average value of 0.02% about 103 days after injection. This type of ammonia became stable until 28 days after injection and did not change appreciably in the wrapped bales and bag silos (Table 1).

The amount of straw-bound ammonia can be estimated by air-drying a sample in an oven and measuring the increase in the nitrogen content of the treated materials. The amount of absorbed and straw-bound ammonia was calculated to be about 70 and 20% of the total amount, respectively, when an amount of 3% ammonia was used. The residual amount of ammonia injected vaporized and was released during storage. In straw with a high moisture content, a considerable amount of absorbed ammonia easily vaporizes and is released into the atmosphere, especially when combined with the moisture from ponds near the upper surface of the bale or stack when opened. Wastage of ammonia and air pollution can be prevented by avoiding treating straw with a high moisture content and by mixing ammonia in the treated materials with volatile fatty acids (VFAs). Ammonia binds well to the VFAs which are present in the silage. These aspects should be carefully considered as the treatment becomes more popular in Japan.

5) Temperature for treatment

A chemical reaction between ammonia and straw normally occurs faster at higher than at lower temperatures. When liquid ammonia is injected, the temperature increases rapidly, reaching a maximum value 2–6 h after

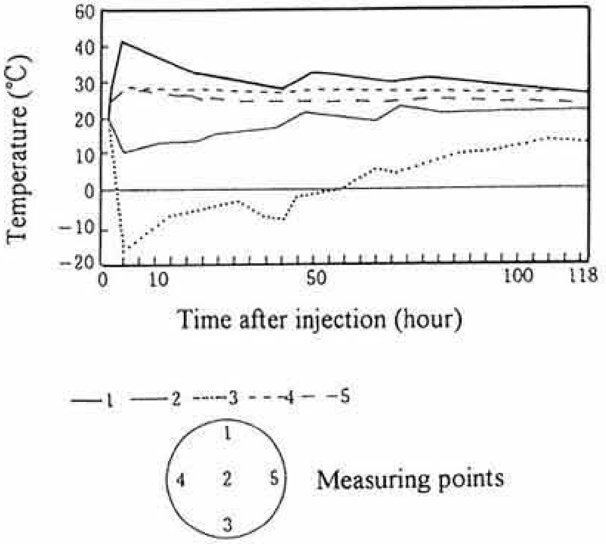

Fig. 4. Changes in temperature at various points in round bale, after the injection

injection. The increase ranges between 40 and 60°C, depending on the following factors: temperature at the onset, amount of ammonia injected, exposure time of the reaction, and moisture content of the treated materials. Due to the combination of internal temperature with radiant heat from sunlight, temperatures above 80°C can occur in the outer layer of round bales. The decrease in temperature also depends on a number of factors causing ambient temperatures to level off at about 15°C. This temperature is normally reached within 1–2 weeks after injection. Liquid anhydrous ammonia is gradually vaporized at the bottom of a stack, leading to a drastic cooling of the surroundings. The temperature at the bottom is below 0°C for 5 days after injection and reaches a value of 15°C (ambient temperature) after an additional 6–7 days (Fig. 4). The time necessary to treat cereal straw depends on the temperature; the lower the temperature, the lower the rate of treatment. Data on the temperature of the treatments revealed that optimum improvement in the feeding value can be achieved after 8 weeks of storage at temperatures below 5°C, between 4–8 weeks at temperatures around 5–15 °C, between 1–4 weeks at temperature from 15–30°C, and at 1 week at 30°C. These findings indicate that effective treatment requires more than 1 month at high temperatures and 3 months at low temperatures. Palatability is also improved when the duration of the period of treatment increases. Colorless and transparent films were initially used, which enhanced the increase of the ambient temperature. In the new injector system, white films were developed and were recommended for use in order to avoid the drastic increase of ambient temperature and toxicity of the treated materials to livestock.

Feeding method of treated cereal straw for cattle and sheep

1) Intake of treated straw

By treating rice straw with ammonia, the TDN (total digestible nutrients) content increased from 40 to 60%. Thus, treated rice straw was found to be similar to good-quality grass hay, while treated barley and wheat straws were similar to grass hay harvested at a slightly later stage. Ammoniated cereal straw offered to ruminants provides a larger source of supplementary nitrogen than grass hay. When fed to animals in higher amounts, supplements of minerals and vitamins are required. Cereal straw contains virtually no vitamins and fewer minerals than does grass hay. According to the practical guidelines for the feeding of ammoniated cereal straw in Japan, the recommended daily allowance of treated roughage was up to 2 kg per day per cow. These guidelines were set mainly because the concentration of ammonia in roughage (dry matter basis) was barely controlled under the conventional method, and was used only as a method of inhibiting mold in damp grass hay. The "HOKUNOU-S" system has been authorized for application to cereal straw, but not to grass hay. Furthermore, since it can only be applied under strict and safe conditions, it may enable to increase the intake of treated straw as ruminant feed, thus lowering the cost of production for beef and dairy cattle operations.

2) Feeding experiment with treated straw given to breeding beef cattle

A 3-year reproduction test using a total of 96 breeding cattle was carried out at the Tokachi Farm of the National Animal Breeding Center and the Hokkaido National Agricultural Experiment Station in Japan. Cattle reared under the system of summer-grazing and winter-housing were fed treated straw during the winter. In these cattle, dry-matter intake of treated straw (6 kg per day), and palatability of treated straw as a basal ration were high (Table 2). The contents of vitamins and miner-

Table 2. Dry matter intake of ammoniated wheat straw

Year	Feeding period	Feeding days	Intake (DM kg d^{-1})
1990	12/17 ~ 5/15	150	7.1
1991	12/ 5 ~ 5/20	167	6.3
1992	11/ 6 ~ 5/29	205	6.2

Table 3. Breeding record of Japanese black beef cattle fed ammoniated cereal straw under a summer-grazing and winter-housing system

Year	Insemination (No. of cattle)	Conception (No. of cattle)	Conception rate(%)	Stillbirth (No. of cattle)	Calving rate(%)	Delivery interval (days)
1990	30	29	96.6	1(1)	93.3	374
1991	33	33	100.0	2(1)	91.2	385
1992	33	33	100.0	2(0)	92.3	363

( ): summer grazing season.

als of the treated straw are lower than those of grass hay. However, by supplementing the ration with vitamins A, D and E, phosphate, calcium, and other minerals, a satisfactory level of breeding efficiency in yearly calving was obtained (Table 3). The occurrence of white muscle disease in calves can be prevented by the addition of selenium in rations, since the selenium levels in the soils of field and cereal straw tend to be very low in Japan. If ammoniated straw is to be used as livestock feed, selenium should be added.

Treatment costs for cereal straw

The treatment costs for cereal straw include the expenses for the purchase or baling of the straw, collection and transfer, and wrapping and ammonia injection. The cost is about ¥ 32 per kg of wheat or barley straw in Hokkaido and if the cereal straw could be home-delivered, the price may be reduced to ¥ 20. The cost varies with the supply and demand of straw, the length of the actual working time of the wrapping machine, and field conditions—wet conditions cause an increase in time leading to the increase of harvesting expenses[8].

Metabolic disorders in cattle fed treated roughages

Only in the last 2 decades has ammoniation of cereal straw and other agricultural by-products been subjected to research for use in animal feed rations. However, in 1984, the first cases of hyperexcitability in cattle and sheep fed on treated roughage were reported, due in large part to the increasing popularity of ammoniation as a method of enhancing the intake and digestion of low quality roughage in ruminants[1,2,6]. The hyperexcitability of ruminants, generally referred to as "Bovine bonkers", is associated with a neurological disorder. Thus, a number of leading factors have been extensively examined, including the method of ammoniation, treatment temperature, level of intake of treated roughage, cereal species and variety, sugar and magnesium contents in the roughage. The possibility of transfer of substances to milk and other animal products should be more thoroughly investigated to ensure the safety of society's food supply.

1) Feeding test for detection of possible toxicity of roughages in Japan

Since the late the 1980s, feeding trials using treated rice, wheat, and barley straw have been extensively conducted on dairy cows and beef cattle in Japan. There have been no reports of the occurrence of metabolic disorders in ruminants fed cereal straw treated with 3% ammonia based on dry matter weight. It was also confirmed that straw treated with an amount of up to 6% ammonia did not show any adverse effect on the health and growth efficiency of steers; the feeding value was found to be as high as that of straw treated with a 3% concentration of ammonia. However, in rare cases where immature grass containing higher levels of soluble sugars was treated even with a 3% concentration of ammonia and was subsequently fed to cows, the suckling calves displayed signs of hyperexcitability[5], presumably due to the passage of toxins in cow's milk. A feeding trial using such toxic grass (treated with a 6% concentration of ammonia) showed a decrease in milk production in young dairy cows compared with previous calvings. Treatment of high-quality immature grass with high concentrations of ammonia was found to be toxic and to have an adverse effect on milk production[4].

2) Practical guidelines for ensuring feed safety

Several important factors must be considered for the ammoniation of crop residues. The feeding system, and type and age of animals are also equally important factors to be considered to determine whether treated roughage will have a toxic effect or cause hyperexcitability. By following a standardized procedure for ammoniation, the occurrence of "Bovine bonkers" can be prevented to achieve safety in animal production and in the supply of wholesome food to the public. It has been demonstrated that in the presence of moisture, ammonia and glucose

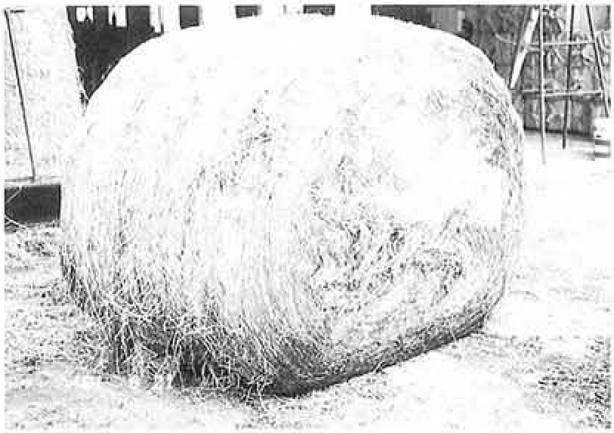

Fig. 5 Moldy roughage that should not be ammoniated

react to form 4-methylimidazole. The 2- and 4-methylimidazole compounds are known to cause convulsions in mice and have been implicated in a clinical poisoning syndrome in cattle. The guidelines for ammoniation recommended in Japan are as follows:

(a) Roughage containing high levels of reduced sugars, including grass and whole crop feeds, should not be subjected to ammoniation. Moldy roughage should be excluded from treatment because it may produce toxic materials (Fig. 5).

(b) The concentration of ammonia administered is normally 3% or less, based on the dry matter of the straw; when the moisture content exceeds 30%, a concentration of up to 4% ammonia is permitted.

(c) Better diffusion of ammonia can be obtained by injecting ammonia into the lower part of round bales and turning the bales upside down.

(d) Treatment at high temperatures should be avoided by using white plastic stretch film and storing feed in a shaded area. It is also recommended to quickly wrap round bales to avoid heating due to respiration and aerobic fermentation.

The contractor must follow these guidelines completely, as required by the legislation concerning feeds and feed additives. The legislation has recently been amended in Japan to include the use of "HOKUNOU-S"-processed ammoniated straw as feed for ruminants.

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