Journal
California Agriculture, 78(1)

ISSN
0008-0845

Authors
Davy, Josh
Doran, Morgan
Macon, Dan
et al.

Publication Date
2024

DOI
10.3733/001c.94527

RESEARCH ARTICLE

Improving the feeding value of rice straw

Treating rice straw with ammonia gas increased its value as cattle feed, including protein content, quantity consumed, and weight gain.

by Josh Davy, Morgan Doran, Dan Macon, Betsy Karle, Glenn Nader, Roger Ingram, Nadia Swanepoel and Peter Robinson

Online: https://doi.org/10.3733/001c.94527

Abstract

For rice producers, removing straw from a field after harvest is important because the material is slow to break down and needs to be gone prior to planting the next season. One option is to bale the straw and use it as a forage supplement for cattle. Although rice straw is a low-cost supplement, it's also low in forage quality and digestibility. Three trials over a four-year period tested methods to improve rice straw forage quality in the field where it was harvested, and then tested the treatments in cattle feeding trials to assess intake by cattle, performance in weight and size gain, and forage quality. The goal was to find an economical method to improve rice straw feeding value that was also practical to implement for both rice farmers and beef cattle producers. Of the treatments tested, treating traditionally baled rice straw with ammonia gas improved crude protein, intake and cattle performance, compared to untreated straw. The treatment achieved the goals of being easily transported, practical to implement, and cost effective.

Removing rice straw from recently harvested rice fields is an increasingly important management approach. The material is slow to decompose due to its high silica content, which can affect planting the following season. Burning straw stubble in the field was a common practice for many decades, but is now regulated and limited by the California Air Resources Board. One popular option has been to bale the straw for use as livestock forage. Rice straw is a low-cost feed for ruminant livestock, but the poor forage quality and low digestibility due to the high silica content limits the use and acceptance of rice straw as a cattle feed. The focus of this research was to find methods to increase the feeding value of rice straw so that it can be better used as a livestock feed. This is particularly important during times of drought when traditional feed sources are in short supply and alternative feeds are more expensive than usual.

Ammoniating rice straw proved to be a practical and economical method of increasing the straw's forage value and intake. *Photo:* Josh Davy.

Three trials over a four-year period (2014–2017) have led to practical recommendations for managers who are interested in feeding rice straw to livestock. These trials are unique in that they were conducted at a field level, where approximately 170 acres of rice straw was harvested, baled and bagged on private commercial rice fields in the Sacramento Valley each year. The treatments were applied at the harvest sites and the straw was then hauled to the University of California Sierra Foothill Research and Extension Center (SFREC) in Browns Valley, California, where feed trials were conducted.

One of the key elements tested to improve rice straw quality was the use of high-moisture straw (< 60% dry matter) compared to low-moisture straw. Prior forage testing by the research team concluded that the quality of rice straw dropped quickly as the straw dried after rice grain harvest (Drake et al. 2002). However, a comparison of differing moisture levels in rice straw fed to live cattle has not been formally evaluated. Traditionally, high-moisture forages are susceptible to mold, which can be detrimental to livestock health. To prevent potential toxicity, multiple experimental treatments were applied to high-moisture straw to protect the forage from developing high levels of mold.

Cattle consuming straw from the ammoniated treatment gained significantly more weight throughout the trial period than cattle in the other three treatments.

Ammoniating rice straw (using anhydrous ammonia) has shown promise for improving rice straw forage value in California (Toenjes et al. 1986) and in other countries (Sarnklong et al. 2010). Ammoniation involves the injection of ammonia gas into a sealed forage stack. The gas subsequently dissipates around the stack, but remains underneath the plastic wrapping that seals the stack. The addition of ammonia increases nitrogen and the resulting crude protein of the straw. Differing straw treatments (table 1) were applied in 2014 and 2015, followed by a comparison of the most promising treatment in 2017.

Different ways of treating straw

In year one (2014), the trials were composed of three treatments. The following three years were expanded to include four treatments. The first-year treatments were all high-moisture straw (harvested at 48% dry matter, dried to an average of 61% dry matter throughout the trial). The first treatment received a lactic acid bacterial application at the time of baling (Promote Forage-Mate VS-3 Water Soluble at 1.0 grams/ton). The second used a propionic acid application at baling (Promote Forage-Mate Storage-Mate Liquid at 3 pounds (lbs)/ton fresh crop). The final treatment was untreated high-moisture straw as a control.

As the first trial year progressed, the high-moisture bales began to break down and became difficult to handle, which led us to a different strategy for the second year. The second year (2015) straw was baled at 80% dry matter with the hope of maintaining the structural integrity of the bales while preserving the forage quality

TABLE 1. Rice straw treatments by year

Year	Treatment type and amount	Treatment intentions
2014	All treatments baled 2–3 hours post rice harvest at 48% dry matter	
	Lactic acid, 1.0 g/ton	Prevent mold formation
	Propionic acid, 3 lbs/ton	Prevent mold formation
	Control, high-moisture straw not treated	
2015	Straw flail chopped after rice harvest and baled with dew moisture at 20% dry matter	
	Lactic acid, 1.0 g/ton	Prevent mold formation
	Lactic acid + molasses spray, 1.0 g/ton + 1.5 gal/1,000 lbs of straw	Prevent mold, increase protein, energy, and palatability
	Ammoniation of stack, NH_3 at 2% of forage weight	Increase protein and palatability
	Control, no treatment added	
2017	High-moisture treatments at 51% dry matter, low-moisture at 9% dry matter (chopped as in 2015)	
	High-moisture control, no treatment added	
	High moisture + lactic acid, treatment dropped due to inability to bale forage	Prevent mold formation
	Low moisture + ammoniation, NH_3 at 2% of forage weight	Increase protein and palatability
	Low-moisture control, no treatment added	

benefits of high-moisture straw. The treatments included lactic acid (same as year 1), the lactic acid treatment plus molasses sprayed onto the straw at the time of baling (1.5 gallons/1,000 lbs straw), ammoniation (NH_3 at 2%), and an untreated control.

Due to early rains and poor field conditions, trials were postponed in 2016. The third trial in 2017 combined lessons learned from years one and two by including previous treatments of high moisture (51% dry matter) only, high moisture plus lactic acid (later dropped), low moisture as a control (91% dry matter), and low moisture plus ammonia treatments. The high-moisture lactic acid treatment was eventually dropped from the feeding trial due to baling challenges with the high-moisture rice straw.

FIG. 1. Applying lactic acid at baling. *Photo*: Josh Davy.

Harvesting and baling

In the first year, the rice straw was baled at high moisture two to three hours after the combine harvested the rice. The treatments were applied just before the forage was picked up by the baler (Massey Ferguson Hesston 2170XD baler) using a tractor-mounted sprayer (fig. 1). Due to the high moisture content of bales, they weighed approximately 1,300 lbs each. The bales were collected from the fields and transported to SFREC near Browns Valley, California. Upon arrival, they were unloaded to create three stacks per treatment of 12 bales each (3 bales high by 4 bales long), covered with five mil black/white plastic (white side out) and weighted around the bottom with tires. All stacks were in an open-sided barn protected from rain, but not from ambient temperature and humidity.

In the second year (2015), the straw was allowed to dry for a day, chopped with a flail mower the following day, and baled with dew moisture the following morning. Allowing the freshly harvested straw to dry for one day made it possible to chop the straw. Chopping wet straw was not possible due to binding and clogging of the flail mower. The chopping process adds a mastication step, which aids digestibility (Nader and Robinson 2008).

Bales were collected from the fields separately for the different treatments. They were stacked in rows that were three bales high and 12 bales long by wrapping (on the day of baling) with a continuous plastic wrapper (Stinger 4010 Cube-Line Wrapper, Stinger, Inc., Burrton, Kan.; figs. 2 and 3), which created one large stack per treatment. The ammonia treatment was injected on the day the bales were wrapped. After 30 days in these stacks, the plastic was cut to create six groups of six bales (with plastic still wrapped around, but not at the exposed bale ends), which were loaded onto flatbed trucks and transported to SFREC. Upon arrival, the stacks were immediately put back together, except that each original stack was divided into three stacks of 12 bales per stack (i.e., three bales high by four bales long), and the junctions were sealed with plastic tape.

FIG. 2. Rice straw being wrapped in plastic. *Photo*: Josh Davy.

FIG. 3. Finished rice straw treatments. *Photo*: Josh Davy.

The third year was harvested in the same manner as year one for the high-moisture treatments (high moisture and lactic acid) and year two for the lower-moisture treatments (ammoniated and control). The rice had lodged, or fallen over, in the field prior to harvest. This caused the combine to harvest the straw at a lower height than is normal, increasing the moisture of the straw. The resulting wet straw was difficult to handle and nearly impossible to bale. Enough straw was baled to include the high-moisture treatment but not the high-moisture treatment that included lactic acid bacteria.

Feeding trials

Each feeding study was completed at SFREC. Animals in each experiment were stratified by body weight to create experimental groups and were randomly assigned to pens. Each treatment included a total of 20 weaned steers (average 650 lbs. starting weight) split into two randomly assigned pens (10 head per pen). Pens were about 60 feet by 30 feet with about 25% covered by a roof (including concrete feed bunks and a concrete floor feeding area). All pens had open water tanks.

All pens received the same grain ration and free choice of their randomly assigned rice straw treatment (fig. 4). All treatments received a ration acclimation period of two weeks prior to what was considered day one of the trial. Daily consumption of straw was recorded for each pen. The concentrate portion of the diet included:

- Flaked corn = 84% – 5.6 lbs/head/day
- Cottonseed = 15% – 1 lb/head/day
- Calcium carbonate = 0.7% – 0.05 lbs/head/day
- Total grain ration of 6.65 lbs/head/day

Cattle performance data were collected on days 0, 14 (day 1 of trial), 45, and 90. Weights were individually recorded in a Silencer squeeze chute, which was validated every 20 head with manual weights (fig. 5). Tailhead height (hip height) and hip width were recorded at the time of weighing, as described by Rauch et al. (2014).

Forage quality analysis

Rice straw treatment samples were obtained on the same days as the animal data were collected. In addition to protein analysis, fiber, pH, energy, mineral values, yeast and mold were analyzed to understand the safety of the high-moisture forages being fed to cattle. Fiber is measured as neutral detergent fiber (NDF), which can be used as an estimate of intake. Higher NDF values translate to lower intake. Energy is reported as total digestible nutrients (TDN). Mold and yeast samples were given three serial dilutions through the rice straw sample to be plated and incubated for five days on a potato dextrose agar prior to counts (Rock River Laboratory 2017).

FIG. 4. Cattle consuming rice straw in feed trial. *Photo*: Josh Davy.

FIG. 5. Collecting weight and hip width measurements. *Photo*: Josh Davy.

Statistical analysis

Statistical analysis of all straw descriptors utilized the MIXED procedure of SAS (2014), with treatment as a fixed effect and time post-baling as a repeated effect, as well as the interaction of treatment and time. The PDIFF option was used to differentiate the effects of treatments, and linear and quadratic polynomial contrasts were used to describe linear (Day-L) and quadratic (Day-Q) effects of time post-baling. All values within the replicated stack were averaged prior to statistical analysis by using ‘stack’ (i.e., 2 stacks/treatment) as the statistical replicate.

Statistical analysis of all animal-based descriptors utilized the MIXED procedure of SAS (2014) with pen and treatment as fixed effects and steer-within-pen as a random variable. Statistical analysis of all pen-based descriptors utilized the GLM procedure of SAS (2014) with treatment as the fixed effect. The third-year statistics were analyzed by the same method using StatGraphics (StatPoint 2009).

High-moisture results (year 1)

The animals’ average daily weight gain the first year was significantly affected by treatment ($P = 0.05$), by period ($P \leq 0.01$), and by the treatment/period interaction ($P < 0.01$). The periods were broken up by the first and last half of the feeding trial, with weights taken at midpoint. In the first period, cattle in the control group (untreated high-moisture straw) outgained cattle in the other treatment groups by approximately 0.5 pound per day. During the second period, cattle consuming the diet containing rice straw treated with lactic acid bacteria outgained the other two treatment groups by up to one pound per day (table 2). Treatment did not significantly affect hip width ($P = 0.22$) or tailhead height ($P = 0.34$).

Forage quality was affected by treatment, but the differences were small and did not fully explain the weight and size gain differences observed (table 3). Across both periods, average daily consumption of free-choice fed straw was 11 pounds per head per day for both the control and propionic acid treatments. By contrast, the lactic acid treatment averaged 17.74 pounds per head per day ($P = 0.04$). No differences in the feed-to-gain ratio existed when comparing the lactic acid treatment against the control ($P = 0.96$). This further highlights that the difference in gain was likely not due to forage quality, but rather simply to intake. As would be expected, mold levels increased as the trial progressed ($P < 0.01$), which would help explain why the differences of intake and performance were not apparent in the lactic acid treatment until the second period.

Low-moisture results (year 2)

The ammoniated treatment was the only treatment that added performance value to the dry straw in the year two trial (table 4). Cattle consuming straw from the ammoniated treatment gained significantly more weight throughout the trial period than cattle in the other three treatments ($P < 0.01$). Pen-level intake data corroborated these findings, as cattle in the ammoniation treatment had significantly higher straw intake and gain-to-feed ratio than the other treatment groups ($P < 0.05$).

Combining treatments (year 3)

As seen in the second year, the ammoniation treatment resulted in a 0.6 lb/head/day higher weight gain compared to the control dry straw treatment, and 1.4 lb/head/day higher results than the high-moisture straw treatment. The ammoniated treatment also significantly increased hip width, but not hip height (table 5).

The high-moisture straw treatment had higher NDF and mold counts, and lower TDN (energy) values. The two low-moisture treatments were not different in any of these measures. The ammoniated treatment was higher in crude protein than all other treatments (table 4).

TABLE 2. Average daily gain of differing treatments to high-moisture rice straw

Average daily gain	Control	Propionic acid	Lactic acid bacteria	Standard error
Period 1*	1.9[b]	1.44[a]	1.4[a]	
Period 2	0.23[a]	0.33[a]	1.33[b]	0.132

* Within a row, values with the same letter are not different ($P > 0.05$). Period 1 includes days 0–45, period 2 includes days 45–90.

TABLE 3. Year 1 mean forage quality and mold/yeast values of differing treatments of high-moisture rice straw across both periods

	Control	Propionic acid	Lactic acid bacteria
Intake lbs/head/day*	11.4[a]	11.3[a]	17.7[b]
Dry matter, %	60.9[a]	63.6[a]	61[a]
pH	8.06[a]	7.54[a]	7.96[a]
ADF, %	40.7[a]	38.1[b]	39.0[b]
aNDF, %	61.7[a]	58.9[b]	59.1[b]
Crude protein, %	5.3[a]	5.0[a]	5.4[a]
Mold, million cfu/g	3.4[a]	2.6[a]	1.5[b]
Yeast, million cfu/g	2.8[a]	2.5[a]	2.0[a]

* Within a row, values with the same letter are not different ($P > 0.05$).
ADF = acid detergent fiber; NDF = neutral detergent fiber.

TABLE 4. Average daily gain and intake of differing treatments of low-moisture rice straw in year 2

Measures	Control	Ammonia	Lactic acid	Molasses
Average daily gain, lbs/day*	1.15[a]	1.72[b]	1.26[a]	1.12[a]
Intake, lbs/day	7.7[a]	9.7[b]	8.09[a]	8.7[a]
Gain to feed ratio, %	8.5[a]	11.0[b]	8.9[a]	7.7[a]

* Within a row, values with the same letter are not different ($P > 0.05$).

TABLE 5. Least square mean gain, growth and forage quality between rice straw treatments in year 3

Measure	Control - low moisture	Ammoniated - low moisture	High moisture
Average daily gain, lbs*	1.1[b]	1.7[c]	0.3[a]
Hip height change	1.6[a]	1.4[a]	1.1[a]
Hip width change	1.4[ab]	2.1[c]	0.7[a]
Intake lbs/head/day	9.6[b]	12.0[c]	7.8[a]
Crude protein, %	3.98[a]	8.42[b]	4.86[a]
NEg, Mcal/lb	0.18[b]	0.19[b]	0.07[a]
Total digestible nutrients, %	50.3[b]	50.6[b]	44.4[a]
Neutral detergent fiber, %	58.4[a]	58[a]	60.4[a]
Mold, million cfu/g	0.48[a]	0.01[a]	4.5[b]
Yeast, million cfu/g†	1.9[b]	0.002[a]	0.42[a]

* Within a row, measures with the same letter are not different.
† Although low-moisture yeast levels were higher in the first two samplings, no difference between treatments was seen in the third sampling (all treatments < 0.5).
NEg = net energy for gain.

Increasing the feeding value of rice straw so that it can be better used as a livestock feed is particularly important during times of drought when traditional feed sources are in short supply and alternative feeds are more expensive than usual. *Photo*: Josh Davy.

Real-world challenges

In the first year, mold levels likely affected forage intake. Forage samples cored from the bales in the lactic acid treatment had significantly lower mold counts compared to the other two treatments (table 3). Cattle selectively consume forages with less mold, and that effect can only be negated by differences in forage quality, which was not seen between our straw treatments (Wittenberg et al. 1996). Although the lactic acid treatment helped suppress mold in wet straw in the first year, this was not the only problem encountered with wet straw.

The goal for the final year of the project was to combine and compare the most successful treatments from the first two years. Unfortunately, the wet straw treatment proved impractical to bale due to binding in the baler; it became impossible to harvest enough straw to include the high-moisture lactic acid treatment. One explanation may be that, in this particular year, the straw had fallen over in the field prior to harvest, which caused the cutting height of the combine to be lower than in the first year. This lodging of the rice at harvest was not a problem encountered the first year. As seen during the first year, mold was a significant issue in the high-moisture treatment straw (without lactic acid) that could be baled. Perhaps the lactic acid treatment would have preserved the value of the high-moisture straw again in the third year, had it been possible to implement.

Our multi-year efforts indicate that the most consistent and practical treatment is to allow straw to dry after harvest, flail chop the straw, bale it with a small amount of dew moisture, and then ammoniate the straw.

The real-world nature of this research provides a benefit to those who may implement the treatments. The challenges we encountered during the trial would also happen in practice. Not only was high-moisture straw extremely difficult to bale in the final year, it also added an extra burden during rice harvest on growers who cooperated in the trial. The advantage of the dry straw was that it allowed growers to complete the time-sensitive rice harvest activities, then come back to harvest the lower-value rice straw later. If high-moisture treatments are desired, we suggest that they only be attempted when two circumstances are present: the combine can harvest the rice at a high cutting height and a lactic acid treatment (or any other method that limits mold) can be applied. Additionally, the high-moisture bales lost their integrity approximately 30 days after baling. Thus, they would have to be stored close to where they are fed to livestock; otherwise, they would be too difficult and dangerous to handle.

The lack of increased intake of the molasses-treated straw in the second year was surprising. When opening the bale, the molasses could be felt throughout, indicating uniform distribution of the treatment application. However, the practicality of this treatment at field scale is questionable. If straw that was sprayed in the windrow (cut hay rows prepared for baling) with molasses was not baled immediately after spraying, it would quickly harden and clog up the baler.

The only observable measure that differed between the low-moisture straw treatments was the apparent protein augmentation (table 5) resulting from the ammoniation process that imparts non-protein nitrogen in the straw. Augmented protein increases the intake and utilization of low-quality forage in tall-grass prairie (Köster et al. 1996). The novelty of this research was applying this concept to an even lower-quality forage. Despite the low quality of rice straw, the feeding trials with rice straw reproduced the effects observed with protein augmentation of tall grass, showing increased intake and subsequent weight and size performance with ammoniated straw during both years of feeding trials. The effect is particularly evident because the grain portion fed to all treatments met individual animal protein requirements. This means the steers in the trial desired the added protein even though it was in excess of their dietary needs.

Although successful, the ammoniation process had a learning curve. During the 30-day period post-ammoniation, the stack smoldered and began to catch fire. Inspection of the straw indicated that it had been wrapped tightly and the ammonia probes had been placed deep into the stack. This did not allow the gas to fully dissipate around the stack. The smoldering occurred only where the ammonia tubes had been placed into the straw. Loosely wrapping or tarping the stack, and injecting the ammonia at multiple locations, would lessen the direct amount of ammonia at a single location and allow the air to move freely for better dissipation. This would alleviate worries of causing fire.

Higher intake and weight gain

Multiple years of harvesting and feeding trials indicate that increasing rice straw forage intake in beef cattle is possible. Our multi-year efforts indicate that the most consistent and practical treatment is to allow straw to dry after harvest, flail chop the straw, bale it with a small amount of dew moisture, and then ammoniate the straw. Practical implementation showed that this treatment was manageable in the field at harvest time and produced repeatable results in cattle feed intake and weight and size performance. The dry straw was also easier to transport, allowing it to be used broadly in both beef and dairy rations. The resulting rice straw product appears to be an acceptable feed source for ruminant livestock on a non-gaining maintenance diet. CA

J. Davy is UC Cooperative Extension (UCCE) Livestock Advisor for Tehama, Glenn and Colusa counties; M. Doran is UCCE Livestock Advisor for Yolo, Solano and Napa counties; D. Macon is UCCE Livestock Advisor for Placer and Nevada counties; B. Karle is UCCE Dairy Advisor for Glenn and Tehama counties; G. Nader is UCCE Livestock Advisor Emeritus; R. Ingram is UCCE Livestock Advisor Emeritus; N. Swanepoel is Visiting Fellow in the UC Davis Dept. of Animal Science; P. Robinson is Extension Nutritionist in the UC Davis Dept. of Animal Science.

The research team owes considerable gratitude to the Parker, LaGrande, and Holzapfel families for their amazing contributions to this research, particularly for being so accommodating during the stressful time of rice harvest. We also thank the Rice Research Board for funding these feeding trials, and those that preceded it, which built the knowledge necessary to get this far. Finally, we thank the diligent staff at the Sierra Foothill Research and Extension Center for the efforts to set up and daily manage the feeding of the livestock.

References

Drake DJ, Nader GA, Forero LC. 2002. Feeding rice straw to cattle. UC ANR Publication 8079. https://anrcatalog.ucanr.edu/pdf/8079.pdf

Köster HH, Cochran RC, Titgemeyer EC, et al. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J Anim Sci 74(10):2473–81. https://doi.org/10.2527/1996.74102473x

Nader GA, Robinson PH. 2008. Effects of maceration of rice straw on voluntary intake and performance of growing beef cattle fed rice straw-based rations. Anim Feed Sci Tech 146(1-2):74–86. https://doi.org/10.1016/j.anifeedsci.2007.12.007

Rauch RE, Cun G, Nader GA, Robinson PH. 2014. Effects of rice straw versus wheat straw in a total mixed ration on intake, digestibility, and growth of Holstein heifers. Anim Prod Sci 54(8):1047–55. https://doi.org/10.1071/AN13298

Rock River Laboratory, Inc. 2017. Anti-nutritional measures. Visalia, Calif. https://rockriverlab.com/pages/Anti-Nutritional-Measures.php

Sarnklong C, Cone JW, Pellikaan W, Hendriks WH. 2010. Utilization of rice straw and different treatments to improve its feed value for ruminants: A review. Asian Austral J Anim 23(5):680–92. https://doi.org/10.5713/ajas.2010.80619

SAS Institute Inc. 2014. SAS/SHARE software: Release 9.4. Cary, N.C. https://documentation.sas.com/doc/en/pgmsascdc/9.4_3.5/shrref/titlepage.htm

StatPoint Technologies, Inc. 2009. Statgraphics Centurion XVI user manual. Warrenton, Va. https://cdn2.hubspot.net/hubfs/402067/PDFs/user-manual.pdf

Taylor RE, Field TG. 1999. Beef Production and Management Decisions (3rd ed.). Upper Saddle River, N.J.: Prentice Hall. 714 p.

Toenjes DA, Bell M, Jenkins B. 1986. Baler ammoniation of rice straw: One alternative to burning. Calif Agr 40(5-6):15–17. https://calag.ucanr.edu/download_pdf.cfm?article=ca.v040n05p15

Wittenberg KM, Undi M, Bossuyt C. 1996. Establishing a feed value for moulded hay. Anim Feed Sci Tech 60(3-4):301–10. https://doi.org/10.1016/0377-8401(96)00985-6