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ABSTRACT

In Arkansas, silage is typically stored as balage in long rows of round bales wrapped in plastic film. It is important to evaluate the aerobic stability of this fermented forage when it is exposed to air, especially during the winter months when most of it is fed to livestock or sold as a cash crop. Two types of forage, orchardgrass (Dactylis glomerata) and wheat (*Triticum aestivum*), were harvested in May 2002 and stored as balage. Twenty-one bales of each balage type were unwrapped and exposed to air on 10 Dec. 2002 for 0, 2, 4, 8, 16, 24, or 32 d to evaluate aerobic stability. For both orchardgrass and wheat balage, final bale weight, dry matter (DM) content, and pH were not affected ($P > 0.05$) by exposure time. Across both balage types, DM recoveries were ≥97% for all bales, indicating that both types of balage were very stable when exposed to air. Concentrations of neutral detergent fiber (NDF) and 48-h ruminal in situ digestibility were not affected ($P > 0.05$) by exposure time for either balage type. Concentrations of N were greater ($P = 0.045$) for orchardgrass balage exposed to air for 16 d or longer compared to balage sampled at exposure (d 0), but this response was not observed ($P > 0.05$) for wheat balage. These results suggest that the balage evaluated in this trial was very stable after exposure to air for up to 32 d. This should allow for considerable flexibility with respect to feeding, transport, and marketing of balage during winter months without significant aerobic deterioration.

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MEET THE STUDENT-AUTHOR

Robert T. Rhein

I graduated from Mountain Home High School in Mountain Home, Ark., and plan to graduate from the University of Arkansas in May 2004 with a B.S. degree in animal science. Currently, I am a full-time employee in the Department of Animal Science where I work as a farm manager for the Forage Research Area. I have been a full-time employee since 1998. My responsibilities at the Forage Research Area include the feeding and care of more than 200 dairy heifers and the management of all hay and silage production at the unit. Since harvesting different types of forage as hay or silage comprises a large portion of my work responsibilities, I am very familiar with many of the problems experienced by producers. As a cattle producer myself, I enjoy doing research that addresses these issues. Storing harvested forages as balage is a growing trend in Arkansas, but only minimal research has been conducted that specifically addresses problems associated with this technique. I have assisted with numerous research projects over the past six years, and I wanted to work on a project that would benefit local producers. The knowledge and experience I have gained from this project will help me in my occupation and has motivated me to pursue a masters degree. I would like to thank Dr. Wayne Coblentz for all the knowledge, guidance, time, and labor that he has contributed toward this project.

INTRODUCTION

Silage can be made from any forage that is harvested with low dry matter (DM) content and stored under anaerobic conditions. In this process, sugars are converted to lactic acid by lactic-acid producing bacteria that were associated with the forage in the field. In the upper South, silage is commonly made from cool-season forages, such as alfalfa (*Medicago sativa*), orchardgrass, tall fescue (*Festuca arundinacea*), annual ryegrass (*Lolium multiflorum*), or various cereal-grains. Warm-season forages that are ensiled commonly throughout the region include corn (*Zea mays*), milo or sorghum-sudangrass (*Sorghum bicolor*), and pearl millet (*Pennisetum americanum*). Historically, precision-chopped forages have been fermented and stored in: 1) piles on the ground covered with dirt or plastic; 2) horizontal trench or bunker silos; 3) plastic bags or tubes that can be up to 150 m in length; and 4) upright silos made of metal or concrete. Regardless of methodology, the ultimate goal is to eliminate oxygen from the silage mass and maintain these anaerobic conditions until the silage is fed to livestock. If silage is exposed to oxygen either during or after the fermentation process is completed, aerobic deterioration will ultimately occur. Common indicators of aerobic deterioration include mold development, spontaneous heating, DM loss, elevated pH, and reduced forage quality.

The storage of harvested forages as fermented silage has several advantages over storage as dry hay. A primary consideration is associated with the unstable weather conditions that often occur in the spring. Typical weather patterns in April and early May are often rainy with cool temperatures. This increases drying time and makes it very difficult to achieve the level of dehydration necessary for safe storage of dry hay. This level of dehydration is approximately 80% DM for conventional rectangular bales (Collins et al., 1987), but large round bales are more prone to spontaneous heating (Montgomery et al., 1986) and need to be drier (82 to 84% DM) for safe storage. The negative consequences of baling hay before it is adequately dried are widely known to producers, and they include molding, spontaneous heating, undesirable changes in forage quality, and potential for spontaneous combustion (Rotz and Muck, 1994). Producers are often faced with the choice of baling hay before it is dried adequately or risking damage to the wilting forage by rainfall events. When rainfall events occur prior to baling, wilting forages suffer losses of plant sugars and other water-soluble nutrients via leaching and prolonged or reactivated plant or microbial respiration (Rotz and Muck, 1994). Plant sugars are assumed to be completely digestible by ruminants, and forage nutritive value is therefore reduced. In contrast, forages harvested as silage need only to be wilted to about 40% DM, which can be achieved almost independent of the weather. Therefore, forages conserved as silage can preserve plant nutrients and partially avoid dependence on good drying weather.

Recently, an alternative approach has been developed that allows small-sized producers to bale long-stem forages in round-bale form and then wrap them in plastic. The plastic wrap around these bales is essential to establish and maintain anaerobic conditions. This form of storage, often called balage, has become very common in northwest Arkansas. Balage is often stored in long rows of bales that are wrapped with an in-line bale wrapper. This is very convenient and efficient at harvest, but leads to possible problems at feeding, especially when the balage is marketed as a cash crop. Once a long row of balage is opened, oxygen has access to the exposed silage and aerobic deterioration can occur if the balage is not fed or sold quickly. The longer the exposure time, the greater the chance that forage quality will deteriorate. For small producers with a very limited number of animals to feed, exposure time can be weeks or longer. Producers interested in marketing balage as a cash crop often inquire whether balage will remain stable during loading, transport, and subsequent feeding operations at the buyer's facility. Currently, the aerobic stability of exposed balage, particularly during winter months when most of this product is fed or sold, remains unclear. Our objectives were to evaluate the aerobic stability of orchardgrass and wheat balage exposed to air during December and January.

MATERIALS AND METHODS

Forages, Ensiling, and Storage

On 6 and 7 May 2002, 'Benchmark' orchardgrass and an unstated cultivar of soft-red winter wheat were harvested with a mower conditioner (Model 1411; Ford New Holland, Inc., New Holland, Penn.) and allowed to wilt to an appropriate DM concentration for ensiling as balage. The orchardgrass was harvested at the heading stage of growth, while the wheat was harvested at milk stage. When the forages had been wilted to the desired DM concentrations, they were raked into windrows with a New Holland Model 258 side-delivery rake. Immediately after raking, forages were packaged into 1.2 x 1.2-m round bales (Model XL604; Vermeer Manufacturing Co., Pella, Iowa). Bales were hauled out of the field and wrapped with six layers of plastic film (Sunfilm; AEP Industries, Inc., Mt. Top, Penn.) on an in-line bale wrapper (Reeves Manufacturing Ltd., Miscouche, PE, Canada). The bales were positioned in rows on a concrete pad with each row containing only one forage type. Bales remained there, undisturbed, until 10 Dec. 2002.

Exposure to Air

On 10 Dec. 2002, the plastic wrap covering each row of at least 23 bales of wheat or orchardgrass balage was cut and removed. The bales at the end of each row were discarded. The 21 internal bales in each row were sampled (Star Quality Samplers, Edmonton, AB, Canada) on one side with an 0.45-m bale probe to determine the DM content of the bales at the time of exposure. Bales were blocked, based on position in the row, and designated for a second sampling after either 0, 2, 4, 8, 16, 24, or 32 d of exposure. Since these bales were to be evaluated over a 32-d period, holes created by the initial core sample were filled with spray foam insulation to prevent air access into the core of the bale.

Initial Bale Evaluation

At exposure (d 0), bales were removed from the concrete pad, weighed, and placed on individual wooden pallets in an open-air pole barn. This method of stacking allowed air space between bales and ensured equal air exposure for all bales. Bale width and diameter were measured, and the volume and DM density of each bale were calculated. Bales exposed to air for 32 d were fitted with thermocouple wires that were inserted into the core of each bale in order to monitor changes in internal bale temperature over time. Bale temperatures were taken once daily with an Omega 450 AKT Type K thermocouple thermometer (Omega Engineering, Stamford, Conn.).

Final Bale Evaluation

Each bale of both forage types was evaluated a second time after 0, 2, 4, 8, 16, 24, or 32 d of exposure to air in order to evaluate aerobic stability over time. On each sampling date, three bales of each forage type were removed from the barn and weighed. The bales were core sampled on the opposite side of the bale from the initial 0.45-m core sample taken on d 0. A portion of each forage sample was dried under forced air at 50°C to determine the final DM content of each bale; the other portion was used to determine silage pH with a portable pH meter (Model AP5, Denver Instruments, Arvada, Col.). In addition, the three orchardgrass and wheat bales sampled on each of the seven sampling dates were appraised visually for mold and aerobic deterioration on a scale of 1.0 to 5.0, where 1.0 = ideal and 5.0 = white mold and/or other evidence of aerobic deterioration covering the entire outside surface of the bale. Increments of 0.25 were used during the evaluation process.

Forage Nutritive Value

Dry forage samples were ground through a Wiley mill (Arthur H. Thomas, Philadelphia, Penn.) fitted with a 1-mm screen and subsequently analyzed for N, neutral detergent fiber (NDF), and 48-hour ruminal in situ DM disappearance. Analysis of NDF was conducted using batch procedures outlined by ANKOM Technology Corp. (Fairport, N.Y.) for an ANKOM200 Fiber Analyzer. Total N for each silage sample was determined by combustion (Elementar Americas, Inc., Mt. Laurel, N.J.). Silage samples were incubated in the rumen of two fistulated steers for 48 hours to provide an estimate of digestibility for each forage (Turner et al., 2003). The University of Arkansas Institutional Animal Care and Use Committee approved surgical procedures for cannulations and the subsequent care of the fistulated steers.

Statistics

Data were analyzed as a randomized complete block design with three replications. Each balage type was evaluated independently. Single-degree-of-freedom contrasts were used to evaluate the effects of exposure time on each response variable. Contrasts included linear, quadratic, and cubic effects of exposure time; in addition, all exposed bales (2, 4, 8, 16, 24, or 32 d) were compared with bales sampled at exposure (d 0). Significance was declared at P = 0.05.

RESULTS AND DISCUSSION

Initial Bale Characteristics

Within balage type, no contrast differed (P > 0.05) with respect to bale characteristics at the time of exposure to air (Table 1). This was expected because silage generally remains stable during storage unless the anaerobic environment is compromised. Generally, both orchardgrass and wheat bales had virtually identical measurements of diameter, width, and volume. This also was expected since the bale size was pre-set electronically, and each bale was processed, wrapped in plastic, and stored in an identical manner. Although balage types were not compared statistically, the orchardgrass bales were numerically heavier (674 vs. 459 kg) when the silage plastic was removed. Part of the advantage in weight observed for the orchardgrass balage was associated with DM content; the mean DM content for orchardgrass at exposure was 8.0 percentage units lower than for wheat (62.4 vs. 54.4%; Table 1). However, differences in bale weight between orchardgrass and wheat bales were not explained entirely on the basis of differences in concentrations of DM. The DM density of orchardgrass bales ranged from 202 to 235 kg/m^3 compared to only 165 to 187 kg/m^3 for wheat. The DM density of the wheat bales was within the acceptable range (150 to 190 kg/m^3) for round-bale silage reported by Savoie and Jofriet (2003), while the orchardgrass bales were substantially denser. High bale or silage density is known to be effective at reducing the permeability of the silage mass to oxygen, thereby reducing subsequent microbial respiration, elevated internal bale temperatures, and DM loss (Pitt, 1990).

Internal Bale Temperatures

Generally, elevation of bale temperatures would be expected in bales undergoing aerobic deterioration (Pitt, 1990), but there was relatively little temperature response over the 32-d exposure period. One of the wheat bales monitored for 32 d exhibited some increase in internal bale temperature, but this response was not observed until the bale had been exposed for at least 3 weeks. The elevated temperature in this specific wheat bale was an exception to the normal lack of response for nearly all other wheat and orchardgrass bales. Internal bale temperatures did fluctuate somewhat with changes in ambient air temperature; however, this would be expected, especially during a December and January exposure period when the ambient air temperatures can be very low.

It is not surprising that the bale exhibiting elevated internal temperatures was comprised of wheat forage. Orchardgrass bales were packaged at a substantially higher DM density that should theoretically reduce permeability of the air and limit potential for heating via respiration. Many cereal grains, including wheat, have hollow stems, which results in a bulkier forage that is difficult to pack (Coblentz et al., 2001). This is reflected in the lower DM density of wheat balage (Table 1), and the increased likelihood of elevated internal bale temperatures relative to orchardgrass balage.

Final Bale Characteristics

For both orchardgrass and wheat (Tables 2 and 3), there were no changes (P > 0.05) in bale weight, concentration of DM, or pH over the 32-d exposure period. All recoveries of DM were ≥ 97% (Tables 2 and 3), which is near complete recovery and suggests that both balage types were very stable after exposure to air. The linear (P = 0.011) and quadratic (P = 0.036) decreases in DM recovery over the 32-d exposure period that were observed for orchardgrass represented a very small range

(97.3 to 100%) and were probably not biologically meaningful. Similarly, the cubic ($P = 0.034$) response observed over time for wheat balage comprised a similar small range (97.0 to 100%) and also was probably of limited importance. Visual mold scores were very low (≤2.17) for all bales of both types, indicating the balage was well preserved at exposure and showed little sign of deterioration thereafter. No contrast was significant for wheat ($P > 0.05$), but a cubic ($P = 0.009$) response over exposure time was observed for orchardgrass. However, visual mold scores for the orchardgrass balage were extremely low, and the overall range was very narrow (1.08 to 1.42).

Final Bale Quality

Exposure time had no effect ($P > 0.05$) on concentrations of N, NDF, or digestible DM for either orchardgrass or wheat balage (Table 4). Although not compared statistically, orchardgrass balage had substantially higher concentrations of N than did wheat balage (overall means = 2.16 and 1.23%, respectively), but these differences are not related to the silage fermentation process. Generally, the very limited responses over the exposure period further indicate that these bales were very stable after exposure to air during December and January.

Conclusion

Overall, this experiment showed that well-preserved wheat and orchardgrass balages were very stable for more than a month after exposure to air, and this could provide considerable flexibility for feeding, transport, and marketing during winter months without significant aerobic deterioration. It is important to emphasize that the exposure period occurred during the winter months when temperatures were low. It should not be inferred that aerobic stability would be the same during other months when temperatures were substantially warmer.

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Table 1. Physical characteristics of orchardgrass and wheat balage opened on 10 Dec. 2002 and designated for exposure for 0, 2, 4,8, 16, 24, or 32 d. Within forage type, no contrast[z] evaluated was significant ($P > 0.05$).

Exposure time	DM[y]	Diameter	Width	Volume	Weight (wet)	DM Density
d	%	------------- m -------------		m^3	kg	kg DM/m^3
			Orchardgrass			
0	51.0	1.31	1.24	1.69	674	202
2	53.1	1.32	1.23	1.69	713	224
4	58.2	1.31	1.25	1.68	677	235
8	54.8	1.32	1.23	1.69	668	216
16	51.2	1.32	1.24	1.70	698	210
24	56.4	1.33	1.25	1.73	698	226
32	56.4	1.34	1.26	1.77	671	215
SEM[w]	4.81	0.02	0.015	0.050	17.5	14.4
			Wheat			
0	65.8	1.37	1.24	1.84	459	165
2	60.0	1.39	1.23	1.88	547	171
4	63.5	1.38	1.25	1.89	538	181
8	60.9	1.39	1.24	1.87	566	178
16	62.0	1.37	1.24	1.82	514	175
24	62.8	1.37	1.23	1.81	541	187
32	62.1	1.37	1.24	1.84	538	183
SEM[w]	3.89	0.013	0.015	0.046	62.2	11.9

[z] Contrasts for each forage type include: linear, quadratic, and cubic effects of exposure time, as well as a comparison of all exposed bales (2, 4, 8, 16, 24, or 32 d) vs. bales sampled at exposure (d 0).

[y] DM, dry matter.

[w] SEM, standard error of the mean.

Table 2. Characteristics of orchardgrass balage after exposure to air for 0, 2, 4, 8, 16, 24, or 32 d.

Exposure time	Bale weight (wet)	Visual score	DM[z]	DM recovery	pH
d	kg		%	%	
0	674	1.25	52.2	100.0	5.31
2	711	1.17	54.1	99.7	5.12
4	677	1.25	59.5	100.0	5.04
8	662	1.08	56.4	100.0	5.26
16	693	1.25	52.2	99.7	5.78
24	686	1.42	58.8	100.0	5.04
32	647	1.08	56.9	97.3	4.84
SEM[y]	17.9	0.075	4.82	0.57	0.305
Contrasts	------------------	------------------	P > F	------------------	------------------
linear[x]	NS[w]	NS	NS	0.011	NS
quadratic[x]	NS	NS	NS	0.036	NS
cubic[x]	NS	0.009	NS	NS	NS
all exposed vs. 0-d[v]	NS	NS	NS	NS	NS

[z] DM, dry matter

[y] SEM, standard error of the mean

[x] Linear, quadratic, or cubic effects of exposure time

[w] NS, nonsignificant ($P > 0.05$)

[v] Contrast of bales exposed for 2, 4, 8, 16, 24, and 32 d vs. bales evaluated immediately (d 0)

Table 3. Characteristics of wheat balage after exposure to air for 0, 2, 4, 8, 16, 24, or 32 d.

Exposure time	Bale weight (wet)	Visual score	DM[z]	DM recovery	pH
d	kg		%	%	
0	459	1.17	64.8	99.3	5.37
2	550	1.33	58.2	98.7	5.39
4	532	1.42	63.8	98.3	5.41
8	557	1.08	59.2	97.0	5.15
16	517	1.33	61.3	99.3	5.35
24	535	1.33	65.8	100.0	5.52
32	505	2.17	64.8	98.0	5.60
SEM[y]	58.7	0.375	3.53	0.95	0.239
Contrasts	------------------------	------------------------	P > F	------------------------	------------------------
linear[x]	NS[w]	NS	NS	NS	NS
quadratic[x]	NS	NS	NS	NS	NS
cubic[x]	NS	NS	NS	0.034	NS
all exposed vs. 0-d[v]	NS	NS	NS	NS	NS

[z] DM, dry matter

[y] SEM, standard error of the mean

[x] Linear, quadratic, or cubic effects of exposure time

[w] NS, nonsignificant (P > 0.05)

[v] Contrast of bales exposed for 2, 4, 8, 16, 24, and 32 d vs. bales evaluated immediately (d 0)

Table 4. Final characteristics of nutritive value for orchardgrass and wheat balage exposed to air for 0, 2, 4, 8, 16, 24, or 32 d.

	Orchardgrass			Wheat		
Exposure time	N	NDF	Digestibility	N	NDF	Digestibility
d	---------------------	---------------------	% of DM	---------------------	---------------------	---------------------
0	1.96	65.0	78.2	1.28	66.2	73.6
2	2.16	65.3	78.7	1.25	63.6	76.2
4	2.15	67.3	77.8	1.22	64.2	75.5
8	2.18	67.5	78.4	1.27	62.2	76.0
16	2.24	67.4	77.9	1.20	65.3	74.8
24	2.30	65.3	80.5	1.14	61.4	76.2
32	2.15	66.3	79.6	1.22	64.9	75.5
SEM[z]	0.103	1.24	0.83	0.044	2.49	1.70
Contrasts	---------------------	---------------------	---------------------	P > F	---------------------	---------------------
linear[y]	NS[x]	NS	NS	NS	NS	NS
quadratic[y]	NS	NS	NS	NS	NS	NS
cubic[y]	NS	NS	NS	NS	NS	NS
all exposed vs. 0-d[w]	NS	NS	NS	NS	NS	NS

[z] SEM, standard error of the mean.

[y] Linear, quadratic, or cubic effects of exposure time.

[x] NS, nonsignificant (P > 0.05).

[w] Contrast of bales exposed for 2, 4, 8, 16, 24, and 32 d vs. bales evaluated immediately (d 0).