HARVEST AND STORAGE LOSSES ASSOCIATED WITH MID-SIZE RECTANGULAR BALES

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ABSTRACT. *Bale chamber and pick-up losses were determined for small rectangular, large round, and mid-size rectangular balers. In addition, storage characteristics of alfalfa bales formed with small and mid-size rectangular balers were measured. The mid-size rectangular baler produced similar pick-up losses, but had 56% lower bale chamber losses than the other two balers. Also, the quantity of losses produced by the mid-size baler was less sensitive to bale moisture than the other two balers. Mid-size bales exhibited a greater degree of heating and greater dry matter loss during storage than small bales. Mid-size bales stored individually heated less than those stored in stacks. Mid-size bales exhibited lower nutrient retention than small bales, especially those mid-size bales stored at higher moistures.*
Keywords. *Balers, Harvesting losses, Storage losses.*

Since the mid-1980s, sales of large round balers have exceeded those of small rectangular balers. However, many dairy farmers prefer hay packaged in small rectangular bales. Some of the reasons for this preference are that small rectangular balers have lower harvesting losses than large round balers (Koegel et al., 1985), typical indoor storage losses with small bales are lower than outdoor storage losses with large round bales (Collins et al., 1987), and handling, feeding, and processing with total-mixed-ration (TMR) processors is more easily accomplished with small bales, especially in stanchion barns with limited space. Additionally, the use of a small rectangular baler was shown to be more profitable than the use of a large round baler (bales stored outdoors) in a simulation study of a dairy farm (Rotz et al., 1989).

The recent development and marketing of mid-size (~ 800 × 900 mm, ~ 32 × 36 in. bale cross-section) and large (~ 1 200 × 1 200 mm, ~ 48 × 48 in. bale cross-section) rectangular balers is partially in response to some of the drawbacks to large round bales listed above. Because mid-size rectangular bales are typically stored indoors, storage losses should be less than round bales stored outdoors. One slice of a mid-size bale is approximately the same mass as a small rectangular bale, so feeding in stanchion barns and processing in TMR processors should be less problematic than with large round bales. Additionally, because mid-size balers do not require stopping for tying like large round balers, field productivity should be greater with the mid-size baler. Finally, mid-size and large rectangular bales more efficiently fill the available shipping volume on trucks compared to large round bales.

Traditionally, small rectangular balers have been configured with a large diameter pick-up offset from the tractor centerline. The incoming windrow is transferred across the width of the machine and fed into the side of the bale chamber which is located directly behind the tractor. Losses typically occur at two locations on these balers, at the pick-up and the bale chamber. The large diameter pick-up requires the hay windrow to be bent at a considerable angle as it is lifted into the feed system, possibly breaking off brittle leaves in the process. Leaves that are separated from the stem due to the impact of the plunger in the bale chamber may be lost through openings in the bottom of the bale chamber.

A more recent small rectangular baler design uses a bale chamber that is fed from below rather than from the side. This bottom-fed-chamber baler was found to reduce pick-up and bale chamber losses by 17 and 14%, respectively, compared to a conventional side-fed-chamber baler (Shinners et al., 1992). Pick-up losses were less because the smaller diameter pick-up on the bottom-fed-chamber baler allowed for a more gentle flow of the windrow into the baler. Bale chamber losses were less because as the plunger impacted the hay, shattered material was caught in the incoming windrow rather than falling from the machine. Because mid-size rectangular balers currently on the market are configured similarly to the bottom-fed-chamber small rectangular baler, losses from the mid-size balers could be less than that from a conventional small rectangular baler or a large round baler.

Numerous researchers have studied baler pick-up and chamber losses. Pick-up losses have ranged from 1 to 5% of total dry matter, with a mean value of 2% while bale chamber losses ranged from 1 to 7% of total dry matter (Buckmaster et al., 1990). Bale chamber losses were found

Article was submitted for publication in June 1995; reviewed and approved for publication by the Power and Machinery Div. of ASAE in November 1995.

Research supported by Hatch Project No. 1708, College of Agriculture and Life Sciences, University of Wisconsin, Madison; and the J. I. Case Co., Racine, Wisconsin.

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to be well correlated with hay moisture, where lower moisture produced greater losses (Buckmaster et al., 1990).

Design differences between the small rectangular, large round, and mid-size rectangular balers may lead to differences in pick-up and bale chamber losses. Also, because mid-size bales typically have greater density than either small rectangular or large round bales, bale storage characteristics should be different. Therefore, a study was undertaken to quantify some performance differences between these baler configurations. Specifically, the objectives of this study were to compare pick-up and bale chamber losses of the above balers; and bale storage characteristics such as heating, dry matter loss, and nutrient retention for bales formed by small and mid-size rectangular balers.

PROCEDURE

BALERS

Relevant specifications of the balers are provided in table 1. Because all three balers were designed to produce different density bales, no attempt was made to produce bales of similar density. However, all bales were formed with approximately a constant feedrate by operating the machines at ground speeds of about 6.5 km/h (4.0 mph). The mid-size baler used a bale chute to deposit bales on the ground while the small rectangular baler used a bale ejector.

Tests were conducted at either the University of Wisconsin-Arlington or West Madison Agricultural Research Stations using first, second, or third crop alfalfa at about one-fourth to one-half bloom. The alfalfa was dried in a swath and raked into windrows at about 40% moisture content wet basis (w.b.). Crop yield was such that single windrows from a 3.7 m (12 ft) cut width provided adequate feed rate.

PICK-UP LOSSES

Third crop alfalfa at approximately one-fourth bloom was cut with a 3.7 m (12 ft) mower-conditioner and immediately placed into a 2.1 m (7 ft) swath on a 30 m (100 ft) long porous plastic strip for drying. This procedure is described in detail in Shinners et al. (1990). After the material dried to about 30% moisture, the sides of the plastic strip were brought together such that the swath was "raked" into a windrow about 0.9 m (3 ft) wide. This form of windrow formation may have lowered total losses because a rake was not used, however, this 'loose' windrow may have caused greater pick-up losses. When the material had reached baling moisture about three days after cutting, alternate strips were baled with each baler. The balers were equipped with devices to catch losses from under the baler (see Bale Chamber Losses section). Therefore, all material remaining on the plastic strip was either losses from the baler or the mower-conditioner. Mower-conditioner losses were determined and assumed equal for all plastic strips. Therefore, differences could be attributed solely to differences in pick-up losses. The bales obtained from each plastic strip were weighed, samples were collected using a boring device and moisture content of these samples was determined by oven drying at 103°C (217°F) for 24 h in accordance with ASAE Standard S358.2 (ASAE, 1993). The loss material was collected, oven dried at 65°C (149°F) for 72 h and then weighed. Pick-up loss was expressed as a percent of the total dry weight of hay collected from each plastic strip. A total of five replicate tests for each baler type were conducted on 27 August 1993.

Table 1. Baler specification comparisons

	Mid-size Rectangular	Large Round	Small Rectangular
Bale chamber size, mm (in)	800 × 875 (31 5 × 34.5)	1525 × 1145* (60 × 45*)	355 × 460 (14 × 18)
Plunger frequency, strokes/min	41		80
Pick-up width, mm (in.)	2315 (91)	1425 (56)	1880 (74)
Number of tine bars	4	4	6
Tine spacing, mm (in)	66 (2.6)	63 (2 5)	63 (2 5)
Number of tines swept per unit distance,† tines/m (tines/ft)	11.5 (3.5)	7.8 (2.4)	8 8 (2.7)
Pick-up maximum diameter, mm (in)	241 (9.5)	267 (10.5)	343 (13.5)
Pick-up tine tip speed, m/s (ft/s)	3 9 (12.8)	2 9 (9.5)	2 8 (9.2)

* Bale diameter × bale width.

† Number of times a tine will sweep the ground for a given forward travel distance at 6 4 km/h (4 0 mph).

BALE CHAMBER LOSSES

Bale chamber losses were defined as all plant material lost from beneath the baler excluding pick-up losses. All balers were equipped with a canvas-covered frame to capture material lost from under the baler. On the small rectangular baler, the frame extended from the furthest forward position of the plunger to approximately 300 mm (12 in.) past the bale ejector. On the mid-size rectangular baler, the frame extended from the feed mechanism to approximately 300 mm (12 in.) past the bale chute. This baler was also equipped with canvas skirts to reduce the potential for wind losses. On the large round baler, the loss catch frame extended from behind the pick-up to approximately 300 mm (12 in.) behind the bale chamber.

Second or third crop alfalfa was cut and dried in accordance with the procedure outlined previously. Each baler was used to bale alternate windrows of sufficient length to provide between 15 and 20 small bales or one mid-size or round bale. Approximately 360 kg (800 lb) of hay was baled for each mid-size rectangular bale, large round bale, or group of small rectangular bales.

Each bale or group of small rectangular bales were weighed and samples for moisture determination were collected with a boring device. The moisture of these samples was determined by oven drying at 103°C (217°F) for 24 h in accordance with ASAE Standard S358.2 (ASAE, 1993). The loss material was collected, placed in bags, oven dried at 65°C (149°F) for 72 h and then weighed. The under baler loss was expressed as a percent of the total dry weight of hay collected from the trial. The under baler loss study was replicated six times on 15 July and nine times on 30 July 1993.

STORAGE CHARACTERISTICS

Only small and mid-size bales were used for this portion of the study. First crop alfalfa in the early bloom stage was cut on 21 June 1993 and dried in accordance with the procedure outlined in the Bale Chamber Losses section. Baling was conducted on 23 June 1993 at three times during the day, 1530, 1845, and 2000 h, in order to achieve three different moisture levels. Each baler was used to bale alternate windrows to provide between 30 and 40 small bales or 15 mid-size bales. Approximately 6 Mg (6.5 t) of hay was baled for each moisture group. The bale dimensions and mass were measured to determine bale density.

Within 24 h of formation, randomly selected bales from both balers were sampled for moisture determination with a boring device. These samples were oven dried at 65°C (149°F)for 72 h in accordance with ASAE Standard S358.2 (ASAE, 1993). Nine mid-size bales from each of the three moisture groups were stacked three across by three high. Each stack of nine bales was surrounded on all sides by small rectangular bales that had been in storage for about one year. Nine small bales from each of the three moisture groups were also stacked and surrounded in a similar manner. Six mid-size and small bales from each of the three moisture groups were stored individually rather than in a stack. Mid-size bales stored individually were placed on two small straw bales to prevent bale contact with the ground. Bales were stored in an open front building.

Probes containing four copper-constantan thermocouples were placed into five bales of each of the three mid-size bale stacks and into 15 individually stored mid-size bales, 5 from each moisture group. Thermocouples on these probes were on 250 mm (10 in.) centers with the innermost thermocouple approximately 850 mm (34 in.) from the edge of the bale. Individual thermocouples were placed into five bales of each of the three small bale stacks and into nine individually stored small bales, three from each moisture group. The thermocouples were connected to a stepping switch that allowed a Campbell Scientific model 21X datalogger to record the data from all thermocouples. The datalogger was programmed to control the stepping switch, read the temperatures, and download them to a storage module on a 3-h interval. The temperature data was downloaded from the storage module to a microcomputer for further processing. Bales were placed in storage and thermocouples inserted on 24 June 1993. Thermocouples were removed on 11 August 1993 (47-day data) after it appeared temperatures were remaining relatively constant. The bales were removed from storage on 11 November 1993 and final bale mass was determined.

Samples were taken using a boring device for nutrient analysis, both when the bales were placed into and removed from storage. Samples were taken from each of the mid-size bales with thermocouples so that nutrient analysis and temperature measurements were determined for the same bales. In order not to affect the bale temperature near the thermocouples, the core samples were taken at least 380 mm (15 in.) from the thermocouple location. Because it was felt that the core sample would have affected small bale temperature, samples for nutrient analysis were taken from small bales not used for temperature measurement. However, small bales used for temperature measurement were core sampled when bales were removed from storage. Therefore, for the small bales, nutrient analysis into and out of storage did not occur for the same bales. Core samples were analyzed by the University of Wisconsin Department of Agronomy with wet laboratory determination of crude protein (CP), acid-detergent fiber (ADF), and neutral-detergent fiber (NDF).

Table 2. Bale density comparisons

	Moisture Content	Wet Density		Dry Density	
	(% w.b.)	(kg/m^3)	(lb./ft^3)	(kg/m^3)	(lb./ft^3)
Mid-size rectangular	18.6	214_b	(13.4_b)	174_b	(10.9_b)
Small rectangular	18.0	139_a	(8.7_a)	113_a	(7.1_a)
LSD (P = 0.05)	1.1	9	(0.6)	6	(0.4)

a,b Averages with different subscripts were statistically different at the 95% level.

Statistical Analysis

Because alternate windrows were baled by each baler during the pick-up and under baler loss studies, loss data was analyzed using a paired t-test. Average and maximum bale storage temperature and nutrient data for each bale size/storage method/moisture group were analyzed using analysis of variance. Bale temperature at any given sampling period was defined as the average temperature from the four thermocouples located in each bale. A least squares difference (LSD) was then calculated to determine statistical differences. The LSD indicated no statistical difference at a probability of 5%.

Results

Bale Density

Bales formed by the mid-size rectangular baler had 54% greater wet and dry density than bales formed by the small rectangular baler (table 2). The mid-size baler had a pre-compression chamber located before the bale chamber where hay was collected and compressed by the feeding system. After a certain level of compression was developed, the force of the crop on a sensor door in the bottom of the pre-compression chamber activated a clutch which engaged the stuffer drive. The pre-compressed, fixed volume of crop was then fed into the bale chamber to form each bale slice. The final bale density was controlled by the contracting bale chamber. Contracting force on the sides and the top of the bale chamber was exerted by a micro-processor-controlled hydraulic cylinder. The small rectangular baler did not have a pre-compression chamber and used spring force to contract only the top and bottom of the bale chamber. These design differences resulted in the greater bale density from the mid-size baler.

Pick-up Losses

Mower-conditioner losses on the plastic strip before baling were measured as 2.3% of total dry matter (data not presented). Pick-up losses for the mid-size and small rectangular balers were significantly less than those for the large round baler (table 3). Losses from the mid-size and

Table 3. Pick-up losses

	Bale Moisture Content (% w.b.)	Pick-up Loss (% Total Dry Matter)
Mid-size rectangular	14.4	0.7_a
Small rectangular	14.1	0.4_a
Large round	14.1	2.6_b

a,b Averages with different subscripts were statistically different at the 95% level.

Table 4. Bale chamber losses

	Bale Moisture Content (% w.b.)	Loss Moisture Content (% w.b.)	Bale Chamber Loss (% Total Dry Matter)
Mid-size rectangular	21.9	9.4	0.7_a
Small rectangular	21.0	12.8	1.6_b
Large round	19.9	10.1	1.6_b

a,b Averages with different subscripts were statistically different at the 95% level.

small rectangular balers were less than the mean loss at the pick-up of 2% reported by Buckmaster et al. (1990). Pick-up losses were less for the mid-size baler than the large round baler despite the greater tine tip velocity with the mid-size baler (table 1) which might have been expected to increase shattering losses. The diameter of the pick-up was slightly smaller for the mid-size baler than the round baler, but the difference was not believed to be enough to cause significant loss differences. The greater rotational speed of the pick-up on the mid-size baler did produce a greater number of tines swept through a given distance than the round baler (table 1) and this greater coverage might explain why the mid-size baler had lower pick-up losses.

Bale Chamber Losses

Bale chamber losses were 56% lower for the mid-size baler compared to the small rectangular or large round balers (table 4). This difference is probably attributable to the fact that leaves shattered by plunger impact can be caught in the incoming windrow due to the bottom-fed-chamber design of the mid-size baler rather than fall from the machine as with the side-fed-chamber small baler or large round baler.

Each mid-size bale was formed by about 30 to 35 plunger strokes, or about 0.1 plunger strokes/kg of hay (0.05 strokes/lb). Each small bale was formed by about five to six plunger strokes, or about 0.2 plunger strokes/kg of hay (0.09 strokes/lb). Because each unit mass of hay was impacted by the plunger about half as often during the formation of the mid-size bales, under baler losses were less for this bale type.

The mid-size baler had a pre-compression chamber where a charge of hay was collected before the charge was fed into the bale chamber. Losses below both the pre-compression and bale chamber were quantified separately (table 5). Pre-compression chamber losses were 29% of the total under baler losses. Also, it was observed that this loss consisted almost exclusively of leaves, which is why the pre-compression losses had a lower moisture content than the bale chamber losses.

Bale chamber losses were plotted versus bale moisture content and linear regression performed (fig. 1). The slope

Table 5. Bale chamber and pre-compression chamber losses for mid-size rectangular baler

	Loss Moisture Content (% wet basis)	Loss (% total dry matter)
Pre-compression chamber	7.4_a	0.2_a
Bale chamber	9.9_b	0.5_b

a,b Averages with different subscripts were statistically different at the 95% level.

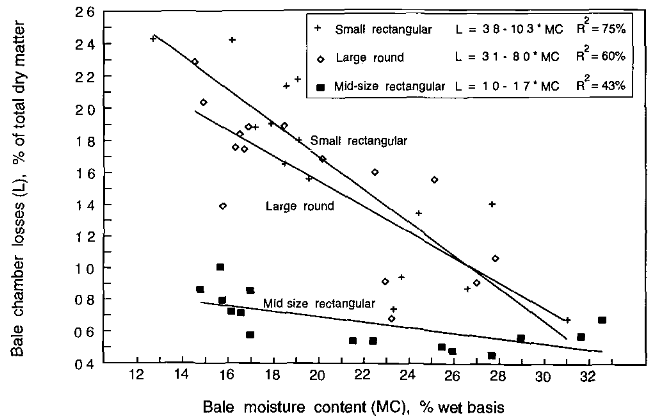

Figure 1–Bale chamber losses vs. bale moisture content for three baler configurations.

of this plot was less for the mid-size baler than the other two balers, indicating that losses from this baler were less sensitive to bale moisture. One reason for this phenomenon might have been that losses occurring due to plunger impact were captured by the incoming windrow due to the bottom-fed-chamber configuration of the mid-size baler. Also, material shattered by plunger impact from near the top of the slice may have been captured before it fell the full 875 mm (34.5 in.) to the bottom of the bale chamber. Although greater leaf shattering may have occurred at lower moistures, the shattered material may not have fallen from the machine because of the size of the bale chamber.

Storage Characteristics

Bale Storage Temperature

For both mid-size and small bale types, three distinct moisture groups were achieved by baling at different times during the day (table 6). Mid-size bales stored in stacks generally had statistically greater average and maximum bale temperature during the storage period than mid-size bales stored individually (table 6, figs. 2 and 3). Mid-size bales at 16.8 and 19.1% moisture had statistically similar average and maximum bale temperature for both storage methods (table 6). Mid-size bales stored individually had similar bale temperatures after about 30 days in storage regardless of bale moisture (fig. 3). Compared to small bales, mid-size bales had a significantly greater number of degree days above 35°C (95°F).

Table 6. Bale heating and dry matter loss as affected by bale type, storage strategy, and moisture content

Bale Size/ Storage Method/ Moisture Group	Initial Bale Moisture Content (% w.b)	Average Bale Temp. (°C)	Maximum Bale Temp (°C)	Heating Degree Days > 35°C (95°F)	Final Bale Moisture Content (% w b.)	Dry Matter Loss (%)
Mid-size/stacked/low	16 8_c	33 5_b	38 4_b	13_b	10 8_a	5.0_{bc}
Mid-size/stacked/inter	19 1_b	35.4_b	41 8_b	22_c	10.8_a	4.4_b
Mid-size/stacked/high	21 2_a	39 6_a	46 2_a	37_d	10 8_a	8 2_d
Mid-size/indiv./low	16 9_c	27.1_c	35 8_{bc}	4_{ab}	11 7_c	4 4_b
Mid-size/indiv./inter	18 7_b	28 7_c	37.3_{bc}	8_{ab}	11.3_b	3 6_{ab}
Mid-size/indiv./high	21.2_a	30 6_{bc}	40 9_b	12_b	12 6_e	15 7_e
Small/stacked/low	15 5_d	21 2_d	26.6_c	0_a	12 5_{de}	0.6_a
Small/stacked/inter.	17.0_c	21 7_d	26 2_c	0_a	15.0_f	1 4_{ab}
Small/stacked/high	21 2_a	23.6_d	30 1_c	0_a	12 4_{de}	0 1_a
Small/indiv./low	15.5_c	20 3_{de}	28 6_c	0_a	12 0_c	3 7_{ab}
Small/indiv./inter	17 0_c	21 6_d	26 2_c	0_a	11 7_c	1.5_a
Small/indiv /high	21 2_a	21.2_d	28 7_c	0_a	12 3_d	0.4_a
LSD (P = 0 05)	0 7	3 2	4 1	10	0 3	3 2

a,b,c,d,e,f Averages with different subscripts were statistically different at the 95% level

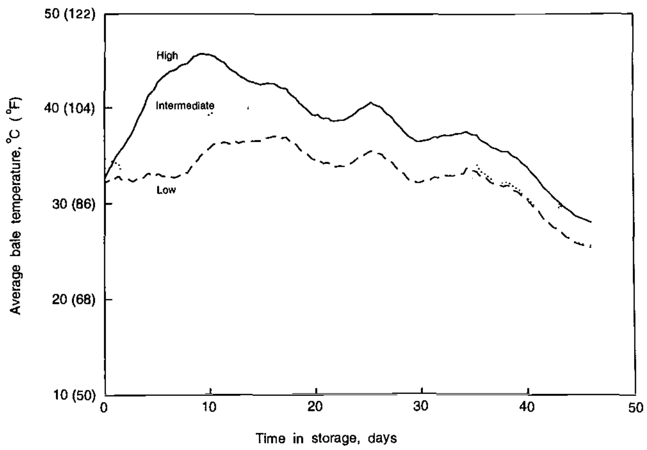

Figure 2–Average bale temperature vs. time in storage for mid-size bales stored in stacks. Average bale moisture contents were: high – 21.2% (w.b.), intermediate – 19.1% (w.b.), and low – 16.8% (w.b.).

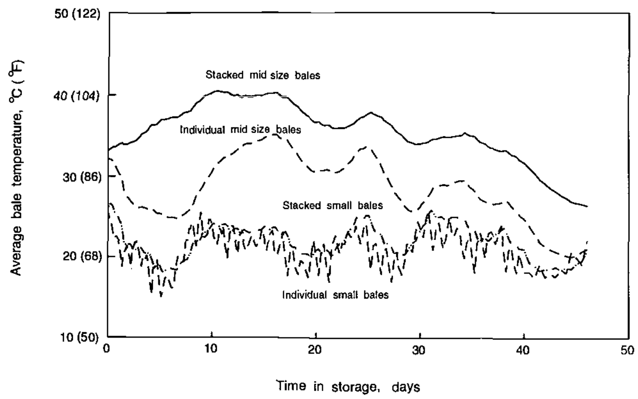

Figure 4–Average bale temperature vs. time in storage for mid-size and small bales stored in stacks and individually. Average moisture for mid-size bales stored in stacks – 19.0% (w.b.), for mid-size bales stored individually – 18.9% (w.b.), for small bales stored in stacks – 17.9% (w.b.), for small bales stored individually – 17.9% (w.b.).

The type of storage and the bale moisture generally had no effect on average or maximum bale temperature for small rectangular bales (table 6). However, small bales always exhibited less heating than mid-size bales independent of storage method or bale moisture (table 6, fig. 4). In fact, mid-size bales stored individually had greater average and maximum bale temperature than small bales stored in a stack.

Nelson (1966) and Buckmaster et al. (1989) both reported that bale moisture was more significant than bale density with respect to small bale heating in storage. However, both researchers found a strong positive correlation between bale heating and density. Heat generation occurs in hay bales when organic matter, primarily carbohydrates, serve as an energy source for microbial respiration. The chemical reaction of respiration involves the conversion of carbohydrates and oxygen into carbon dioxide, water, and heat. This conversion of carbohydrates results in dry matter loss.

In this study, higher density, mid-size bales exhibited greater heating than lower density, small bales stored with the same method and moisture. This could be partially due to two factors. First, for a given volume of hay a greater amount of dry matter and carbohydrates are available in a higher density package. Therefore, greater microbial activity and heating can be expected per unit volume. Nelson (1966) found that the quantity of heat generated per unit mass of alfalfa hay during storage showed an increase with increased bale density. Second, the larger volume of the mid-size bale might have had an adverse effect on heat transfer properties. It might be possible that heat generated in the bales moves to the exterior by conductance and then is transferred to the air and is lost from the stack through air movement in the cracks between bales. With mid-size bales, this transfer might be more difficult due to their greater volume compared to small bales and correspondingly fewer cracks for a given stack volume.

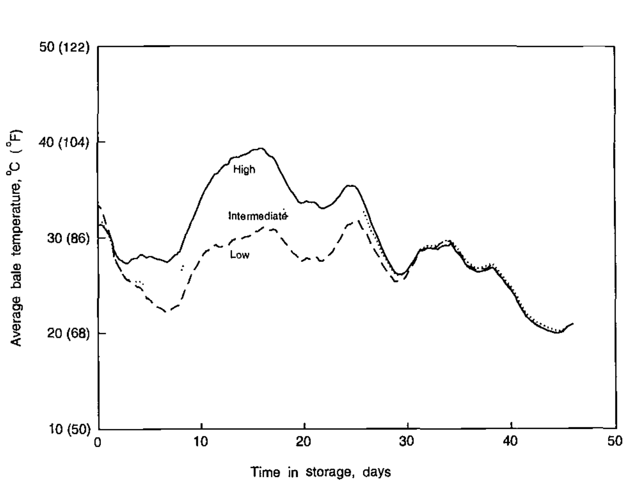

Figure 3–Average bale temperature vs. time in storage for mid-size bales stored individually. Average bale moisture contents were: high – 21.2% (w.b.), intermediate – 18.7% (w.b.), and low – 16.9% (w.b.).

Bale Dry Matter Loss

Mid-sized bales stored at the high moisture range had the greatest dry matter loss in storage (table 6). The mid-sized bales stored individually at the high moisture range had the greatest dry matter loss despite fewer degree days greater than 35°C (95°F) than any of the mid-size bales stored in stacks. It was possible that the combination of heating and freely available oxygen associated with bales stored individually helped to increase the microbial activity and the dry matter loss for these bales. Independent of storage method, dry matter loss for mid-sized bales stored at low, intermediate, and high moistures were 4.7, 4.0, and 12.0%, respectively. The type of storage and the bale moisture generally had no effect on dry matter loss for small rectangular bales (table 6). In all cases, mid-size bales had greater dry matter loss than small bales at corresponding moistures and storage method, however in only three cases was the difference statistically significant. Independent of storage method or moisture, average dry matter loss for small and mid-size rectangular bales was 1.3 and 6.9%, respectively. Buckmaster et al. (1989) reported 2.7% average dry matter loss for small bales below 20% moisture stored in stacks. Mid-size bales have greater dry matter loss than small rectangular bales due to greater microbial activity in the mid-size bales. Because dry matter loss is directly related to the heat generated, it

Table 7. Initial and final quality and storage quality retention

Bale Size/ Storage Method/ Moisture Group	Initial ADF (%)	Final ADF (%)	ADF Retention	Initial NDF (%)	Final NDF (%)	NDF Retention	Initial CP (%)	Final CP (%)	CP Retention
Mid-size/stacked/low	39.4_{bc}	41.8_{ab}	1.06_{bcd}	48.2_{bcd}	52.3_{abc}	1.09_{bc}	17.7_{cd}	17.0_{cde}	0.97_{cd}
Mid-size/stacked/inter.	38.9_{cd}	43.2_{a}	1.11_{abc}	47.8_{cd}	54.3_{ab}	1.14_{ab}	18.0_{abc}	16.4_{cde}	0.91_{de}
Mid-size/stacked/high	36.8_{e}	40.7_{bc}	1.11_{abc}	45.2_{d}	51.5_{bcd}	1.14_{ab}	19.3_{a}	17.4_{bc}	0.90_{de}
Mid-size/indiv./low	39.1_{cd}	42.0_{ab}	1.08_{abcd}	49.0_{bc}	53.8_{ab}	1.10_{b}	17.3_{cd}	16.0_{de}	0.93_{cde}
Mid-size/indiv./inter.	39.3_{bcd}	43.3_{a}	1.10_{abc}	48.0_{bcd}	54.6_{a}	1.14_{ab}	17.5_{cd}	15.9_{de}	0.91_{de}
Mid-size/indiv./high	39.2_{cd}	41.1_{bc}	1.05_{cde}	48.2_{bcd}	51.8_{bcd}	1.08_{bc}	18.0_{bcd}	17.4_{bc}	0.97_{cd}
Small/stacked/low	43.1_{a}	41.0_{bc}	0.95_{ef}	54.2_{a}	50.9_{cd}	0.94_{de}	15.5_{e}	17.1_{cd}	1.10_{ab}
Small/stacked/inter.	41.2_{ab}	39.1_{cd}	0.95_{ef}	51.3_{ab}	49.4_{de}	0.97_{de}	16.7_{de}	18.5_{ab}	1.11_{ab}
Small/stacked/high	37.3_{de}	42.5_{ab}	1.14_{a}	45.4_{d}	53.2_{abc}	1.17_{a}	19.2_{ab}	16.5_{cde}	0.86_{e}
Small/indiv./low	43.1_{a}	43.3_{a}	1.01_{de}	54.2_{a}	54.7_{a}	1.01_{cd}	15.5_{e}	15.8_{e}	1.02_{bc}
Small/indiv./inter.	41.3_{ab}	37.8_{d}	0.92_{e}	51.3_{ab}	46.8_{e}	0.91e	16.7_{de}	18.9_{a}	1.13_{a}
Small/indiv./high	37.3_{de}	42.2_{ab}	1.13_{ab}	45.4_{d}	50.6_{cd}	1.12_{ab}	19.2_{ab}	16.5_{cde}	0.86_{e}
LSD (P = 0.05)	2.0	2.1	0.07	3.2	2.8	0.08	1.3	1.3	0.09

a,b,c,d,e,f Averages with different subscripts were statistically different at the 95% level.

was expected that mid-size bales should exhibit greater dry matter loss than small bales.

Bale Nutrient Retention

Average initial quality constituents were 38.8% ADF, 47.7% NDF, and 18.0% CP for mid-size bales and 40.5% ADF, 50.3% NDF, and 17.1% CP for small bales (table 7). Although material was baled from alternating windrows in the field, the small bales had a slightly lower quality into storage than the mid-size bales. Both NDF and ADF concentrations may have been lower and CP concentrations higher in mid-size bales due to savings of leaf tissue compared to small bales (see Bale Chamber Losses sections).

Mid-size bales had a CP retention ratio of less than one (0.94) which indicates that microbial activity in the hay caused a loss of protein during storage (table 7). Rotz and Abrams (1988) and Buckmaster et al. (1989) indicated that CP loss in small bale storage was relatively insignificant. Generally, the main energy source for microbial activity is carbohydrates and CP is consumed at a lower rate. However, in mid-size bales, heat generation and dry matter loss indicated a high level of microbial action which was evidently great enough to cause a significant CP loss. Neither bale moisture nor bale storage method had a significant effect on CP retention for mid-size bales.

Mid-size bales had an increase in NDF and ADF concentration during storage compared to small bales (table 7). Neither NDF or ADF components are lost during storage but rather dry matter loss in storage is primarily soluble carbohydrates with some loss of CP. Therefore, the increase in NDF and ADF concentration during storage in mid-size bales was due to high dry matter loss with these bales. Similar results were reported by Rotz and Abrams (1988) and Buckmaster et al. (1989) for small bales in storage. Neither bale moisture nor bale storage method had a significant effect on NDF or ADF concentration for mid-size bales.

Average final quality constituents were 42.3% ADF, 53.4% NDF, and 16.9% CP for mid-size bales and 39.7% ADF, 51.3% NDF, and 17.3% CP for small bales (table 7). Therefore, although initial bale quality was slightly higher for mid-size bales compared to small bales due to lower leaf losses with the former machine, final bale quality was slightly lower for the mid-size bales.

Conclusions

- Mid-size bales had 54% greater dry density (174 vs. 113 kg/m^3, 10.9 vs. 7.1 lb/ft^3) than small rectangular bales.
- Pick-up losses were less for the small or mid-size rectangular baler than for the large round baler (0.4 vs. 0.7 vs. 2.6% of total dry matter, respectively).
- Bale chamber losses were 56% less for the mid-size baler than for either the large round or small rectangular balers (0.7 vs. 1.6 vs. 1.6% of total dry matter, respectively).
- Losses from the mid-size rectangular baler were less sensitive to bale moisture than for either the large round or small rectangular balers.
- Mid-size bales had greater average and maximum bale temperature than small rectangular bales stored at similar moisture contents. Mid-size bales stored in stacks had greater average and maximum bale temperatures than mid-size bales stored individually. Mid-size bales greater than 19% moisture stored in stacks had bale temperatures greater than 35°C (95°F), almost 50% of the first 45 days in storage.
- Mid-size bales had greater dry matter loss than small rectangular bales stored at similar moisture contents (6.9 vs. 1.3%, respectively). Dry matter loss was significantly higher for mid-size bales stored at the high moisture range (21%) than those stored at the low or intermediate (17%, 19%) moisture ranges. Dry matter loss was generally independent of the storage method for both bale types.
- High dry matter loss with mid-size bales resulted in increased concentrations of NDF and ADF. High levels of microbial activity as evidenced by greater heating and dry matter loss resulted in a reduction in CP concentration for mid-size bales. Neither bale moisture nor bale storage method had a significant effect on NDF or ADF concentration or CP loss for mid-size bales.

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