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A COMPARISON OF MACHINERY FOR HARVESTING, HANDLING AND FEEDING BOTH MIDLAND BERMUDAGRASS AND LESPEDEZA HAYS IN LARGE PACKAGES

A Thesis

Presented for the

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Degree

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ABSTRACT

Comparative experiments included high density rolls, low density rolls and low density stacks of Midland bermudagrass and Kobe lespedeza hays. Machine performance characteristics and packaging capacities were determined with the different hays. Package characteristics, handling capacities and densities were recorded for each package type. Effects of package type and storage (inside and outside) on curing temperature, depth of spoilage and cattle acceptance were measured. Feeding trials conducted at the end of a three-month storage period determined cattle preference for package type and the amount of hay refused for each package type with both bermudagrass and lespedeza hays.

The low density roll baler had the greatest overall packaging capacity with either grass or lespedeza hay (20.6 metric tons or 22.72 tons per hour). For all machines, the packaging capacity was greater with grass hay than with lespedeza. However, the lespedeza formed into better shaped packages that were easier to move without loss. The best overall handling capacity was with low density, compressed stacks (13.3 metric tons or 14.7 tons per hour).

The curing temperatures in the high density roll bales were greater than in other package types. The high moisture packages had greater curing temperatures than low moisture packages. Hay type had little effect on curing temperatures.

Depth of spoilage was greater for the lespedeza stacks; the high density rolls had the lowest spoilage depths. Spoilage depths were

inversely related to the density of the packages. Density had less effect on spoilage depth for bermudagrass packages because of the thatched covering formed on the outside.

Floored and roofed feed bunks with sliding gate panels kept "trampling" losses below 5 percent. High density packages of lespedeza had less spoilage and were preferred by cattle. When hay packages of equal quality were fed, a preference for low density stacks was noted. High density rolls were more readily eaten by cattle when the rolls were placed on end inside the feeders. The low density lespedeza rolls had the largest amount of hay refused by the cattle. All the hay was eaten from packages stored inside.

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CHAPTER I

INTRODUCTION

Increased grain prices due to fuel and food shortages have focused more attention on low-cost production, harvest and storage of forage crops. Economical hay production is necessary to grow competitively priced beef. Recent development of large-package haying machinery has emphasized reduced labor requirements and outside storage of hay packages. Because of the farmer's desire to rid himself of the physical labor associated with hay harvesting and feeding, he now seems ready to accept the decrease in quality resulting from the outside storage of large packages of hay. Farm equipment manufacturers have introduced several types of new hay packaging machines; the wide choice has left farmers uncertain about which system will best fulfill their individual requirements.

The value of hay produced in Tennessee increased to a total value of over 62 million dollars by 1973. In the same time period the gross value of cattle in Tennessee more than doubled. Hay, once the largest acreage crop in Tennessee, has been surpassed by soybeans in productive acres; however, cattle still remained number one in value of production in 1973 (29).

Hay grown in Tennessee consists of 52 percent grass and legume mixtures, 27 percent legume and 21 percent grass (29). Since large amounts of legumes are used by farmers as a protein source for beef cattle herds, the objective of this study was to examine the baling,

storage and feeding differences between grass and leguminous hays baled with the large-package machines. The three most popular large-package machine types were utilized in this study. The machines had capacity and price ranges suitable for a farmer harvesting 136 metric tons (150 tons) of hay annually for beef cattle consumption.

The three packaging systems used were a high density roll baler with a package density of 128 to 160 kg/m^3 (8 to 10 lbs/ft^3), a low density stacker with a package density of 64 to 80 kg/m^3 (4 to 5 lbs/ft^3), and a low density roll baler having a package density of 80 to 112 kg/m^3 (5 to 7 lbs/ft^3). The systems were compared for packaging capacity and handling capacity to determine baler performance in both types of hay. Feeding trials were conducted to determine cattle preference and the amount of waste due to storage for each system using both types of hay. The types of hay used were "Midland" bermudagrass (Cynodon dactylon (L.) Pers.) and Kobe lespedeza (Lespedeza striata).

CHAPTER II

REVIEW OF LITERATURE

I. THE DEVELOPMENT OF GIANT HAY PACKAGES

Farm families have long dreaded hay harvest time because of the back-breaking work required using traditional methods to preserve winter feed for farm animals. This work is made even more burdensome by the hot weather which occurs during the haying season. These pressures have brought many attempts by ingenious farmers and machinery manufacturers to design and build equipment for easing the work load associated with haying.

Farmers are interested in some method of haymaking that allows mechanical handling in addition to outside storage. The hay packages need to be sufficiently large for efficient mechanical handling and be shaped and compacted to withstand weathering in outside storage without serious loss of quality. A study of early haying methods indicates outside storage is possible through the use of "thatched roof" type stacks. A thatched covering is used in some parts of the world as roofs for houses, so it should also be acceptable for bundles of hay.

The first system involving mechanized hay stacking originated in the Plains States which normally have an abundance of grass hay and rainfall of less than 30 inches per year. In 1958 Martin (17) described a hay cage that could be used for molding a stack into a desirable size and shape. The hay was picked up from the ground and carried to the cage for stacking. The stack could later be moved to a desired location.

More recent models of hay stackers move along the windrow to load and compress hay into a stack-forming chamber. When completed the compressed stack is carried to a desirable location for storage, or it can be unloaded where formed and moved at a later date. Yost (31) reported in 1969 that the compressed, loose stack system could offer substantial labor reduction as a one-man haying system. Bowers et al. (3) reported stacking had two primary advantages: (1) labor reduction and (2) greater flexibility in the types of hay that could be harvested. Bowers also stated that labor required with a stack wagon was about 25 percent of that with traditional baling. Typical labor requirements for conventional harvesting exceeds 2.5 man-hours per ton, whereas the requirement for a stack wagon system varied from 0.4 to 0.8 man-hours per ton, depending on the stack wagon size.

The first work with large round bales was done by Haverdink and Buchele (12) in 1966. They concluded that for mechanized handling, hay should be in small flowable units or large single batches. Their research objective was to form giant bales that would be efficient unit loads for handling equipment and bales that would need little or no protection from the weather. A machine which rolled the hay around hydraulically driven spindles evolved from this work. Four large cylindrical bales were made with the machine in 1966. Problems with maintaining a large, uniformly shaped roll were encountered. By placing a sheet metal shroud in front of the bale and feeding baling twine into the windrow as the bale was formed, the package shape was confined to a uniform cylinder. The twine used was then estimated to cost $1.75 per

ton. Attempts to obtain a desirable bale density were not successful, and the machine was abandoned.

However, manufacturers became interested in the large roll bales and began development of machines to produce them. Two successful large-baler designs were reported by Floyd (9) in 1971. One was a machine built by the Vermeer Manufacturing Company which used a toothed pick-up cylinder to take hay off the ground and move it into a rolling chamber where it was formed into a 900 kg (2000 lbs) bale wrapped with twine. The bale was formed by rolling the hay between two sets of belts. The Vermeer package was 1.8 meters (6 ft) long and 1.5 to 2.1 meters (5 to 7 ft) in diameter. The other design was developed by the Hawk Bilt Company. It was a baler which simply rolled the hay on the ground along the windrow to form a round bale weighing from 450 to 680 kilograms (1000 to 1500 lbs). This package was 2.1 meters (7 ft) long and 1 to 2 meters (3 to 6 ft) in diameter. Based on field observations in Oklahoma from 1971 to 1973, Bowers (2) surmised that one-man haymaking could be feasible with these roll balers.

II. OPERATION AND CAPABILITIES OF LARGE PACKAGE BALERS

New machines have individual operating characteristics and capabilities. Bledsoe et al. (1) compared a Hesston No. 10 Stakhand compressed stack wagon and a Hawk Bilt 480 Roll Baler with a conventional baler equipped with a bale throwing attachment. Midland bermudagrass (Cynodon dactylon (L.) Pers. var. Midland) hay was used. The study showed increased baling and handling capacities for the giant bale machines. Baling at higher moisture levels and the possibility of

using outside storage were other advantages of the low density packages made by the stacker and roll baler. Both Bledsoe et al. (1) and Kilgore (15) found that big packages made from grass 20 to 25 centimeters (8 to 10 in) or less in length were unstable and difficult to handle. From the operator's standpoint, the roll baler was reported to have a longer turning radius than either the conventional baler or the stacker. Dust and chaff proved to be a nuisance when operating the stacker. Operator competence was found to be important in forming well shaped stacks and rolls.

Tests by Bledsoe et al. (1) indicated no significant difference in the packaging capacities of all three machines at a very low hay moisture content (7.2 to 8.9 percent, wet basis). However, at the 15 to 17 percent moisture level, the stacker had a significantly lower packaging capacity than the roll baler. The conventional baler was not used at higher moisture levels. In 1973 tests, the roll bale average diameter was increased to 1.9 meters (6.3 ft) from 1.35 meters (4.4 ft). Packaging capacity was significantly increased by making larger diameter rolls. Kilgore (15) reported packing capacities of 4.5 to 12.7 metric tons (5 to 14 tons) per hour for the roll baler and 3.6 to 6.4 metric tons (4 to 7 tons) per hour for the stacker, depending on the moisture content. Floyd (8) reported packaging capacities of 4.70 to 7.67 metric tons (5.19 to 8.47 tons) per hour for stackers, and Rider and Bowers (24) reported a capacity of 6.8 metric tons (7.5 tons) per hour for large roll balers having a field efficiency of 70 percent.

Bledsoe et al. (1) reported average field losses of 5.2, 3.2 and 1.7 percent, respectively, for the Hawk Bilt 480 Roll Baler, Hesston

No. 10 Stakhand and a New Holland Model 273 conventional baler when baling Midland bermudagrass hay. Kilgore (15) reported that much of the loss for the roll baler came from sluffing of hay from the roll either when the bale was discharged from the baler or when it was later moved.

III. HANDLING AND STORAGE OF LARGE HAY PACKAGES

Several methods have been devised for handling stacks and large round bales. For low density stacks and rolls, the hay must settle and cohere in the packages if losses during moving are to be avoided. Bowers et al. (2) indicated stacks should be left in the field for at least 48 hours before moving. This allows the stack to settle and become more stable. Bledsoe et al. (1) allowed stacks and untied rolls to settle for three weeks before moving.

Rider and Bower's (24) study of roll baling indicated the rolls could be moved with a front-end loader or a three-point hitch mounted mover. Renoll (22) compared handling capacities of two mechanized conventional bale handling systems and a 2.72 metric ton (3 ton) stack system. For a New Holland Baler and Stackcruiser 1047, New Holland Baler and Stackliner 1010, and a Hesston No. 30 Stakhand, one man-hour was required to move 2.67, 1.90 and 3.14 metric tons (2.95, 2.10, and 3.47 tons) of hay, respectively. Bledsoe et al. (1) stated that stack handling capacity was significantly higher than those for conventional and large roll bale systems (rolls moved one at a time) at a baling moisture content of 16 percent (wet basis) or higher. With an average distance of 0.97 kilometers (0.6 mi) from the field to the storage

area, the handling capacity of the Hawk Bilt roll bales was increased from 2.18 to 3.26 metric tons (2.4 to 3.6 tons) per hour when the bale diameter was increased from 1.35 to 1.92 meters (4.4 to 6.3 ft).

Rider and Boyer (26) concluded barn storage was most effective for maintaining total digestive nutrients, minimizing dry matter losses, and preventing an increase in crude fiber for alfalfa roll bales. Protein was best preserved with inside storage for both alfalfa and bermudagrass roll bales. Alfalfa rolls stored outside accumulated additional moisture during storage, especially in the lower 6 inches along the ground. The bermudagrass bales lost moisture during storage and did not exhibit the tendency to retain moisture except in the area immediately in contact with the ground. These events led to the conclusion that outside storage of bermudagrass was feasible and could reduce storage and labor costs. Bledsoe et al. (1) also reported inside storage of grass hay stacks and rolls as being better than outside, but inside storage did not allow baling at greater initial moisture content. The core samples taken from the rolls and stacks at the end of a storage period indicated no significant difference in hay quality when baled at similar moisture levels.

The following recommendations were made by Rider and Boyer (26) for big package storage:

1. Store packages on a well drained site to prevent accumulation of moisture in the lower portions of the packages.

2. Select a storage site near the feeding area to reduce labor.

3. Leave a minimum space of one foot between the packages.

4. Use twine on rolls to reduce wind loss. Plastic twine will not deteriorate and must be removed before feeding.

5. Do not store all hay in one stackyard because of fire hazard and use fire guards to reduce fire hazards.

IV. THE EFFECTS OF MOISTURE CONTENT ON LARGE HAY PACKAGES IN STORAGE

Farmers often wonder when hay is ready to bale, or when the moisture content is low enough to allow the hay package to reach an equilibrium moisture content without damaging the hay quality. Dobie (6) emphasized that hay must be properly raked and baled to return the maximum yields, protein content and gain production in animals. He also indicated that hay raked when too dry (less than 15 percent moisture content), yielded 35 percent less tonnage and the protein loss was greater than for hay of 15 to 20 percent moisture content.

Miller (18) stated that heat generated during the curing period is an indication of microbiological oxidation, resulting in the destruction of dry matter. He further stated that preservative conditions of cured hay exist when a sufficiently high concentration of either sugars or salts occur within the plant material. This condition is reached by the removal of water from the plant juices (solutions of sugars and salts). Once this situation occurs the microbiological action stops. Hay curing is a race between microbiological destruction of dry matter and the preserving process. Consequently the longer the final preserving conditions are delayed, the greater the destruction of dry matter. Miller (18) concludes there may be a transformation from

grass protein to bacteria protein. Therefore, the protein content may not be greatly affected analytically, but the nutritional value may decrease.

Nelson (19) conducted chemical analyses and feeding tests with native grass hay baled at different densities and moisture contents. He stated that high moisture content (above 20 percent) did cause a dry matter loss, however, the crude protein and crude fiber were not affected. Digestibility trials showed a decrease in digestibility of dry matter, crude protein, and gross energy as moisture content increased. Daily gain decreased and feed required per pound of gain consistently increased with increasing moisture content.

Weeks et al. (30) worked with alfalfa in bales and large stacks at different moisture levels. Dry matter losses were reported to range from 4.2 to 9.9 percent in stacks and from 2.1 to 3.4 percent in bales. Digestibility also decreased with increasing moisture content for large stacks, but no such trend was noted for the small stacks. The digestibility was termed good for all stacks, with 60 percent digestibility being excellent. Gains were reported as 0.94 kilograms (2.07 lbs) per day for calves fed high moisture baled hay and 0.71 kilograms (1.56 lbs) per day for those fed loose stacked hay. Mold formation was found in the stacks at the 40 percent moisture level (wet basis), but color was retained well in samples at the 30 to 33 percent level.

Kilgore (15) indicated a decrease in quality in roll bales and stacks as the initial moisture content and density increased. The loss of hay quality, reduction in green color, and unpleasant odor associated

with higher initial moisture content may be attributed to the higher bale densities resulting from the increased compactness and uniformity of packages baled at higher moisture levels.

V. HAY CHARACTERISTICS

The kind of hay processed affects haymaking operations to some extent. Since this investigation compared operations using grass and leguminous hays, the characteristics of the two types of forage crops used are important in comparing results.

Midland Bermudagrass for Hay

Decker et al. (5) stated that Common bermudagrass (Cynodon Daclyon (L.) Pers. Var. Common) was recorded in the United States as early as 1807. Midland bermudagrass is a hybrid produced by crossing Coastal with a winter hardy strain of Common from Indiana. The Midland variety is a tall leafy grass that produces a more open sod than Common bermudagrass. Midland inherited its winter hardiness from its Indiana parent and will consequently thrive without winter kill farther north than Coastal. Fribourg (10) reported that Midland bermudagrass will also withstand the cooler temperatures of elevations up to 1500 feet in Tennessee.

Burns (4) reported Midland bermudagrass being twice as productive as Common in West Tennessee. Both Midland and Coastal exhibit dramatic linear response to nitrogen fertilization. He also advised that bermudagrass reaches its highest quality in late May and early June. Tests at the West Tennessee experiment station have shown that the

cellulose digestibility of Midland bermudagrass hay dropped from 59 percent in late May to 42 percent in early July. Burns suggests making the first cutting for hay when the spring growth reaches 38 to 46 centimeters (15 to 18 in) height. Subsequent cuttings should come every three to four weeks, and the grass should be mowed 5 to 8 centimeters (2 to 3 in) from the ground.

Kobe Lespedeza for Hay

Lespedeza is common to the Southeastern United States. Henson and Hanson (14) recognized annual lespedeza as a major southeastern crop for forage, midsummer and early fall grazing, soil improvement, and hay production. From 1951 to 1960, annual lespedeza was grown on 194.2 hectares (4.8 million acres) in the United States. Only in this country is lespedeza cultivated, and it has been mentioned in our agricultural literature since 1867.

Two species comprise the bulk of useful lespedeza grown in the United States. These are Lespedeza striata (L.) Var. Kobe and Lespedeza stipulacea (P.) Var. Korean. Kobe lespedeza is the most common variety in Tennessee because it grows taller and yields slightly more than other varieties. Pieters (21) stated that lespedeza would grow on almost any type of soil with an average hay yield of about 0.90 metric tons (1 ton) per acre. The best yields are accomplished on good, moist bottom land where yields may reach 2.7 to 3.6 metric tons (3 to 4 tons) per acre. Lespedeza will endure drought, but the amount of growth during a dry season on upland soil is small.

When cut at the proper stage, lespedeza is leafy, with fine stems, such that little plant material is wasted when eaten by cattle. Pieters (21) indicated lespedeza was one of the best hays that could be fed when properly cut and cured. Lespedeza can be cut anytime after the plants reach a height suitable for hay production. The recommended stage for cutting is when the plants are in full bloom or during the early dough stage of the seeds.

VI. FEEDING LARGE HAY PACKAGES

Practical methods for feeding large hay packages have evolved from trial and error approaches. Rider and Bowers (25) stated that feeding losses from round bales could be excessive without proper feeding management. They cited studies at Purdue University that showed 23 to 39 percent savings in wastage by feeding rolls with feeder panels rather than with free choice feeding. Covered feed bunks were reported by Rider and Bowers to further reduce losses by keeping moisture from entering the bale during feeding. Gill (11) reported the use of feeding racks to be generally desirable.

Lechtenberg et al. (16) compared two methods of feeding hay packages from a Vermeer 605 baler, a Hawk Bilt 480 baler, and a Hesston 10 Stakhand. One method was a limited access concept which provided only a few hay packages to cattle at any time. However, cattle were not limited in the amount they could consume from these few packages. The hay was fed in open pasture on sod. The other method utilized racks built into the fenceline and which were designed to give the cows access to three sides of the package. The racks were built on concrete slabs.

Rider and Boyer (26) compared daily hand feeding, free access to bales on sod, and controlled access to bales in feeder panels. They used bermudagrass and sorghum-sudan roll bales.

Feeding studies conducted by Smith et al. (27) compared conventional bales fed on sod, large round bales fed on sod with no feeder panels, and large round bales fed on sod with feeder panels.

Renoll et al. (23) fed johnsongrass hay in conventional bales and in stacks to cattle at Auburn University. The 2.7 metric ton (3 ton) stacks were fed individually in a fescue pasture and the bales were fed free choice from racks.

Feeding wastes varied greatly among the feeding methods used by different researchers. Lechtenberg et al. (16) fed a mixed grass hay in three different types of large packages to groups of 20 Hereford cows. Consumption of the hay when fed in racks was reported to be 96.3 percent. An estimation of the extra waste due to feeding the packages without a rack was made by determining the extra dry matter needed for a cow-day (dry matter consumed by a cow in one day). The amount of hay required without racks was significantly greater ($\alpha < .05$) than with racks for all three package types. The additional hay needed for feeding outside without a rack was 22.6, 35.0 and 38.6 percent for the Vermeer, Hesston and Hawk Bilt packages, respectively. The Vermeer bale losses were significantly lower ($\alpha < .10$). This difference may be attributed to the Vermeer bales being more dense; the rolls retained their shape longer and were less subject to trampling.

The amount of weathered hay was also determined for each of the three packages. The percentages were 12.6, 14.5, and 22.3, respectively,

for the Hesston, Vermeer and Hawk Bilt packages. Weather losses for the Hawk Bilt packages were significantly greater ($\alpha<.10$). This difference was probably due to the very small size of the Hawk Bilt packages (475 pounds). The estimated digestible dry matter losses were 8.8, 8.2, and 12.6 percent for the Hesston, Vermeer, and Hawk Bilt packages, respectively. Again the Hawk Bilt package losses were significantly greater. Even with these indicated differences in hay quality, no significant differences were found among the packages in the hay left in the racks.

Renoll et al. (23) fed 2.7 metric ton (3 ton) stacks and baled hay which had been stored outside with a tarpaulin covering. The loss from feeding the stacks free choice was 42 percent, and the loss from feeding the baled hay in racks was 5.6 percent. An estimated additional 4 percent loss was due to bales rotting on the ground. In this experiment the weather damage to the stacks was estimated to be less than 5.0 percent. Further statements also indicated a significant difference in calf gain and cow loss between the baled and stacked hay.

Rider and Boyer (26) measured wastes due to the feeding methods for both bermudagrass and sorghum-sudan. The waste for free access to rolls fed on sod was 14.6 and 36.0 percent for bermudagrass and sorghum-sudan, respectively. Using feeding panels around the bales and hand feeding into racks gave wastes of less than 5 percent for both types of hay.

If hay is wasted during feeding, this waste must be considered when calculating the actual cost per ton of hay utilized. Smith et al. (27) fed large roll bales with and without feeding panels and

conventional bales on sod to determine the difference in cost per kilogram (2.2 lbs) of gain. The cows utilized 4.13, 8.68, and 6.26 kilograms (9.11, 19.13 and 13.8 lbs) of hay per day, respectively, for bales, roll bales without racks and roll bales with racks. If 226.7 metric tons (250 tons) of hay were utilized per year, the 1974 cost per 45.3 kilograms (hundredweight) of gain would have been $16.14, $20.70, and $12.93 for bales, rolls without racks, and rolls with feeding racks, respectively. Renoll et al. (23) did similar cost studies in 1970 using baled hay fed in racks and stacked hay fed free choice with additional rations of corn and cotton seed meal for both systems. The cost per 45.3 kilograms (100 lbs) gain was $20.53 for baled hay and $26.01 for stacked hay. The cost of harvesting the hay was divided into two categories: (1) tons harvested; and (2) tons actually utilized. The cost per metric ton (1.1 ton) of hay harvested was $16.73 for baled hay and $12.24 for the stacked hay. These figures should be compared with the cost of harvesting each metric ton (1.1 ton) of hay that was actually utilized. These costs were $18.49 for baled hay and $21.01 for the stacked hay. Obviously, the cost of hay actually utilized was greater for the stacked hay because of the waste which occurred when feeding free choice.

Rider and Boyer (26) gave the following recommendations for feeding large hay packages:

1. Control access of cattle to hay.

2. Produce high quality hay since it will be eaten with less waste than will poor quality hay.

3. Feed bales on well drained sites.

4. Limit amount of hay fed at one time to a quantity cattle will consume in one week.

5. Force clean up of hay fed free choice.

6. Use slant bar feeder panels to combine advantages of labor savings and low hay wastage.

CHAPTER III

PROCEDURE

I. DESCRIPTION OF MACHINES USED

Two mower-conditioners were used for cutting the experimental hay plots. The New Holland Model 467 Haybine had a 2.14 meter (7.0 ft) cutting width and was used for both the first cutting of bermudagrass and the single cutting of lespedeza. The second machine was a Gehl Model 990 which had a 2.74 meter (9.0 ft) cut and was used for the second crop of bermudagrass. Both machines were adjusted to cut the hay 5 to 8 centimeters (2 to 3 in) above ground level. The baffles controlling the windrow width were adjusted to allow the hay to fall in a swath 1.52 to 2.14 meters (5 to 7 ft) wide behind the cutter. When the hay was within 10 percent of the desired baling moisture, it was raked with a John Deere Model 640 side delivery rake. The rake was 2.14 meters (7 ft) wide; two swaths were raked into one windrow to collect the hay from a 4.25 meter (14 ft) width of field into each windrow.

The three balers used in this study were a low density stacker, a low density, non-tying roll baler and a high density, tying roll baler.

A Hesston No. 10 Stakhand which produces stacks of hay weighing approximately 1 metric ton (2200 lbs) is shown in Figure 1. The stack dimensions were 2.14 meters (7 ft) wide, 2.44 meters (8 ft) long and 2.44 meters (8 ft) high. The hay was removed from the ground by a flail



FIGURE 1. Hesston No. 10 Stakhand filling the stack chamber during the packaging process.

type pickup mechanism which directed the hay up a duct and into the stack forming chamber. Even filling of the chamber was accomplished by raising and lowering a deflector that directed the hay to the front or rear of the machine. The deflector was controlled remotely by hydraulic cylinder movement of the compression canopy. When the stack chamber was filled with loose hay, the canopy was hydraulically lowered to compress the hay. The chamber was then refilled with loose hay and compressed. This cycle was repeated approximately eight times. When the stack reached the desired size the tail gate was unlocked and hydraulically lifted. The unloading chain in the bottom of the stack chamber was then actuated from the tractor seat as the machine was slowly moved forward. The stack was left sitting behind the stacker near the completion point.

The low density roll baler pictured in Figure 2 is a Hawk Bilt Model 480. This machine produced 360 to 545 kilogram (800 to 1200 lb) bales that were 1.83 meters (6 ft) in diameter and 2.14 meters (7 ft) long. The bale was formed by rolling the hay along the ground with a raddle chain made of 2.14 meter (7 ft) bars with spring toothed tines attached at 20 centimeter (8 in) intervals. The height of the tines from the ground was adjustable to adapt the baler to different stubble heights. Since the raddle chain was driven by a hydraulic motor, the chain speed could be adjusted to the ground speed by a flow meter. Bale diameter was kept uniform by moving in a zig-zag pattern along the windrow. Once the desired bale size had been reached, the tail gate portion of the rattle chain was lifted hydraulically and the baler



FIGURE 2. Hawk Bilt Model 480 baler unloading a completed low density roll bale.

pulled forward. The bale was left behind, and the tail gate lowered to begin the next bale.

The high density roll baler was a Vermeer Model 6050 which was capable of making roll bales weighing from 450 to 680 kilograms (1000 to 1500 lbs) and measuring 1.52 meters (5 ft) long and up to 1.83 meters (6 ft) in diameter. This baler is shown in Figure 3. The hay was picked up from the windrow by a rotating cylinder with spring teeth attached. The hay was passed between large rollers into a rolling chamber formed on the bottom by rollers and on the top by spring loaded moving belts. As with the Hawk Bilt machine, uniform bale diameter was maintained by zig-zagging along the windrow. An indicator on the baler told the operator when the bale was finished and ready for "tying." The "tying" mechanism wrapped baler twine in a helical pattern around the bale. The twine feeder was manually controlled by the operator who determined the number of wraps by the length of time the mechanism was engaged. To eject the bale, the upper rear portion of the baler was lifted hydraulically, allowing the bale to roll rearwardly out of the chamber. When the bale was clear of the machine, the rolling chamber was closed and the next bale started.

Tractors used with these balers were all John Deere models rated 67 kilowatts (90 hp) or more. The stacker required a tractor with dual sets of external hydraulic cylinder ports, while the Vermeer baler utilized only one set of cylinder connecting ports. The Hawk Bilt baler had a self contained hydraulic system powered by a PTO driven hydraulic pump. All three balers required a standard 540 RPM power take-off.



FIGURE 3. Vermeer Model 605C packaging a high density roll bale.

II. PACKAGING THE HAY

The hay in this experiment was obtained from four fields. Midland bermudagrass was on fields numbered 16, 17, and 18 and Kobe lespedeza was on the field designated by the letter "L." Fields 16 and 17 contained 3.24 hectares (8.0 acres) each, and both had good stands of bermudagrass with very little infestation of other grasses or weeds. Field 18 contained 3.72 hectares (9.2 acres) and was heavily infested with johnsongrass. Field "L" contained 3.63 hectares (9.0 acres) and had an excellent stand of lespedeza with a few dominant weeds throughout the field. Also a light infestation of dotter was in the lespedeza field. The bermudagrass was cut when 15 to 18 inches tall, and the lespedeza was cut when the seeds were in the dough stage.

The experimental design called for use of two fields for the bermudagrass hay with two moisture levels in each field. The fields were cut at least one day apart to allow sufficient difference in baling times. The hay was allowed to dry to the high moisture level (25 percent, wet basis), and the balers were used in a random order to package two bales each. When the high moisture bales were finished and the remaining unbaled hay reached 15 percent moisture content, the baling was repeated, again in random order with two bales formed by each baler. This process was repeated for the second field.

The second cutting of bermudagrass and the cutting of lespedeza required a slightly different design because only one field was used. Fields 16 and L were used because the quality of bermudagrass was best on field 16, and field L was the only field of lespedeza convenient to

the storage area. When using only one field for the experiment, the entire field was cut and the balers were again used in random order as the hay approached the desired moisture contents. However, in this case four packages were baled by each baler at each moisture content. An identification tag was attached to each bale as it was finished.

The moisture content of the hay was estimated until actual baling was begun. Samples were taken from the windrow at the beginning and during the harvesting process to obtain an average nominal moisture content. The standard oven-drying method was used to determine the moisture content in percent (wet basis).

Packaging times were recorded for each hay package. These packaging times included turning time and actual baling time. Because of the operators' unfamiliarity with the machines and differences in accumulated hours on each machine, the down times were not included in the packaging times.

III. HANDLING AND STORAGE OF THE HAY PACKAGES

Core samples and volume measurements were taken before the hay packages were removed from the field. The core samples were taken with a Pennsylvania Coring Tool driven by a 1.27 centimeter (0.5 in) electrically operated drill. Three random core samples were taken from each bale and placed in a plastic bag along with a tag having the date and bale identification number. The samples were packed in ice and later refrigerated until they could be analyzed by the Plant and Soil Science Department for color and odor ratings and chemical content.

Volume measurements of each hay package were taken immediately before the packages were moved and weighed. The stacks were moved with the Hesston 10 Stackmover shown in Figure 4. The Vermeer and Hawk Bilt rolls were moved with special attachments for a front-end loader mounted on a 4020 John Deere tractor. The attachment used to move the Vermeer bales was a standard fork lift attachment with the fork length extended to 6 feet. Use of this attachment is illustrated in Figure 5. The Hawk Bilt bales were moved with a front-end loader attachment consisting of a rack with six prongs 2.14 meters (7 ft) long and spaced 45.7 centimeters (18 in) apart. The rack is shown in Figure 6.

The bales were weighed as they were removed from the field. The weighing station was positioned in a convenient location between the fields and the storage area. The scales consisted initially of four Torque-O-Meter portable highway vehicle scales. The tractors could be driven upon the scales with the package resting on either the stackmover or the front-end loader. Tare weights of the tractors were taken at the beginning and the end of the weighing period. After the first cutting, a platform was added to the scales to increase the accuracy of the scales and speed the weighing process. The weight of hay left in the field was estimated as each package was moved.

Handling times were determined by timing the loading and transport operations for each bale. Weighing time was not included, and timing was stopped when the bale was completely unloaded. The average transport distance was 100 meters (110 yards).

Both inside and outside storage of hay packages were included in the experiment. A well drained area covered with bermudagrass sod was



FIGURE 4. Hesston 10 stackmover and a bermudagrass stack.

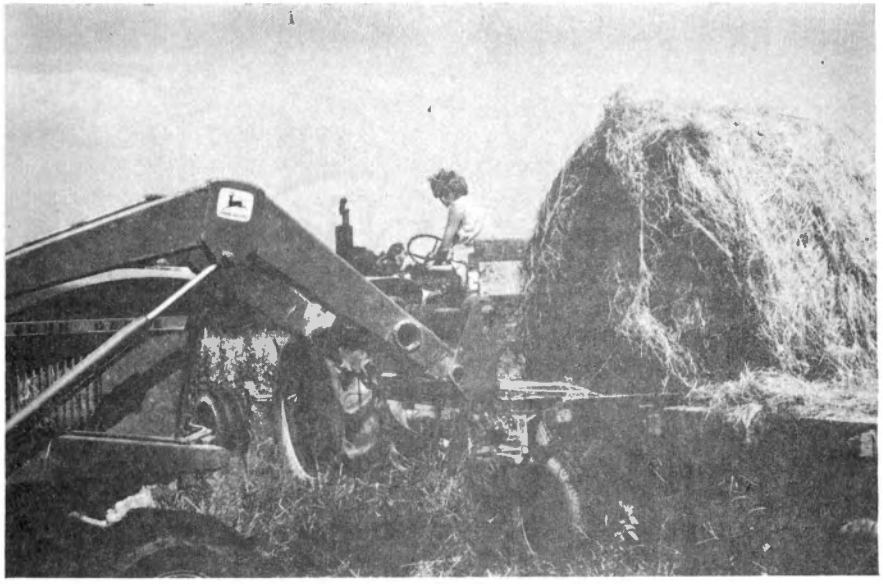

FIGURE 5. Vermeer bale being loaded with forklift attachment.

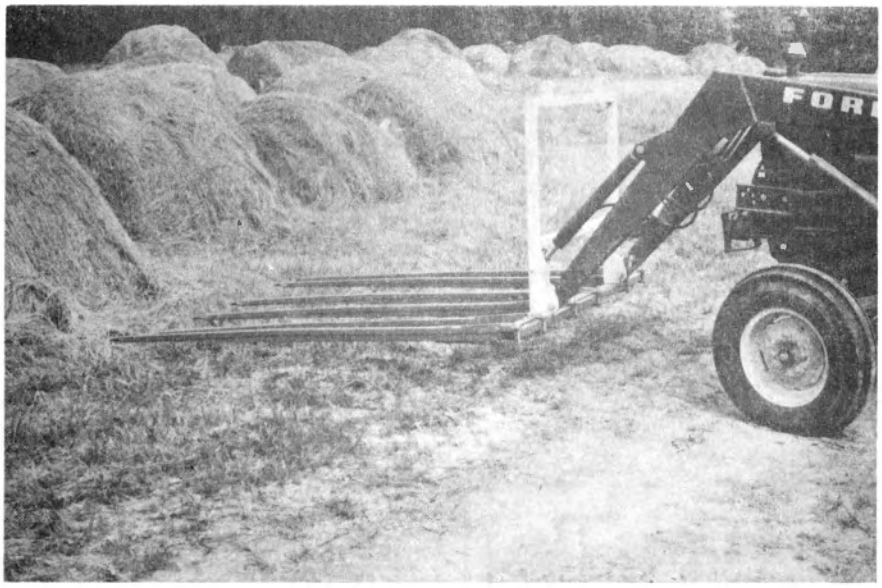

FIGURE 6. Front-end loader mounted hay rack used to move Hawk Bilt bales.

selected for outside storage. Because of the limited amount of barn space, only 25 percent of the hay was stored inside. All packages stored outside were spaced at least one foot apart to allow for water run-off and drying.

Packages designated for temperature measurements were stored around and inside a barn containing a power source and a 24 point recording potentiometer with a voltage regulator. A thermocouple was positioned in the center of a typical package for each combination of treatment variable levels. The treatment variables were packaging machine type, inside or outside storage, and high or low moisture content.

IV. FEEDING LARGE PACKAGES

Core samples were taken again on December 12, 1974, immediately prior to beginning the feeding trials. The samples were taken in the same manner as at the beginning of the storage period. Depth of spoilage measurements were taken on the hay packages by measuring the distance through the wet outside perimeter to the dry hay within the bales. The hay packages were also weighed just before being fed, with the exception of one feeding period when rain prevented the use of scales. The weight of hay fed during this period was estimated from weights taken at beginning of storage, using the percentages of weight change found in similar hay packages used for other periods.

The hay was fed in the sliding gate feeders such as the one shown in Figure 7. The feeder was designed by Dr. B. L. Bledsoe, Associate Professor of Agricultural Engineering at The University of Tennessee. The sliding gates were removable to allow hay packages to be

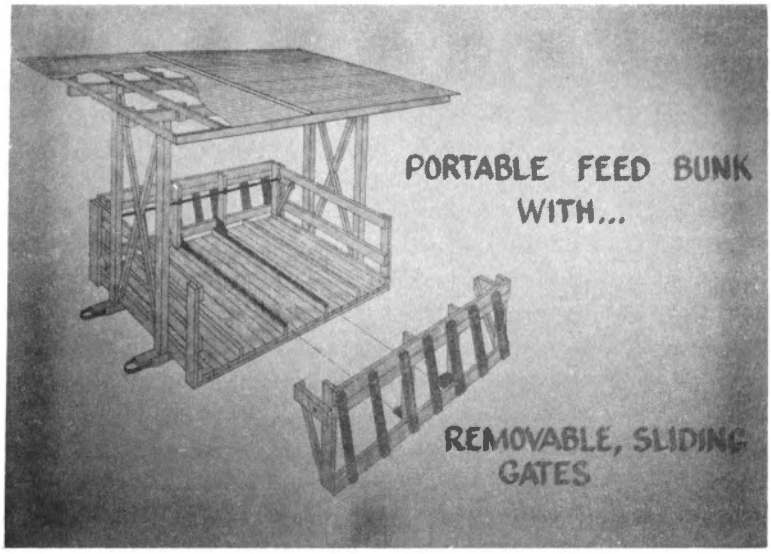

FIGURE 7. Sliding gate feeder used in the feeding trials.

placed in the feeder with either a three-point hitch mounted stack mover or a front-end loader. The cattle naturally pushed the gates inward with their withers to reach remaining hay. Slanted boards were positioned about 40 centimeters (15 in) apart on the gates to keep the cattle from backing out of the feeders and pulling loose hay outside to be dropped on the ground. Figure 8 depicts one of the feeders with a stack placed inside. Six of these feeders were located in a 3.21 hectare (3.0 acre) grass lot with water available from a small farm pond. The feeders were positioned about 6.1 meters (20 ft) apart in a straight line with the sliding gates being parallel to the line.

One hundred and twenty-five 230 to 320 kilogram (500 to 700 lb) Aberdeen Angus steers were enclosed in the feeder lot for the duration of the test. The cattle required approximately one week to consume the six packages of hay placed in the feeders. It was assumed the cattle had consumed all of the edible hay when they left the feeders and began walking the fences looking for feed.

The cattle were fed for four weeks with a different type of hay each week. Hay types used were outside stored bermudagrass baled at low moisture content, similarly stored bermudagrass baled at high moisture content, lespedeza stored outside, and inside stored packages of both bermudagrass and lespedeza.

Each hay package was evaluated for cattle preference by ranking the six feeders from 1 to 6, with 1 being the most preferred, and also by estimating the percentage and weight of the hay remaining in the feeders. These parameters were estimated each day during the first week and every other day during subsequent weeks. At the end of each feeding



FIGURE 8. Hay stack inside a feeder.

period (when the cattle had stopped eating from the feeders), the hay remaining in the feeders was weighed. Estimates were also made of the amount of hay that had been pulled outside the feeder and trampled into the mud.

V. STATISTICAL ANALYSIS

The SAS (Statistical Analysis System) computer program package developed by the Statistics Department at North Carolina State University was used to do the statistical calculations. The SAS program computed analysis of variance tables and means for machine packaging and handling capacities and the package densities. Analysis of variance tables and means were also calculated for the percentages of hay consumed from each package type during the feeding trials.

Data from the first cutting of bermudagrass were not used because of inaccurate bale weights. A 2 X 3 factorial design was used to take and analyze data for the second cutting of bermudagrass and for the lespedeza cutting. A split plot design with hay packages nested within treatments was used to analyze the percentages of hay consumed per day during each week of the feeding trials.

Duncan's New Multiple Range tables were used to determine the mean separation. The temperature, color and odor, depth of spoilage, and waste data were averaged and graphed. All values were calculated both with English and SI (System International) units of measurement.

CHAPTER IV

RESULTS AND DISCUSSION

I. MACHINE OPERATING CHARACTERISTICS IN MIDLAND BERMUDAGRASS AND LESPEDEZA HAYS

The moisture content of the hay affected operating characteristics of the three hay packaging machines more than the type of hay used. Exact hay moisture content was difficult to obtain since no method of rapid moisture determination was available other than estimation. Samples taken from random windrows just prior to baling were analyzed by the Plant and Soil Science Department to determine the percent moisture content (wet basis) by the standard oven drying method. This moisture content was assumed to be that of bales packaged immediately after the samples were taken. These sample moisture contents are tabulated in Table 1. The average moisture contents of the high and low moisture observations were 24.4 and 18.5 percent, respectively, for the bermudagrass and 21.4 and 12.3 percent, respectively, for the lespedeza.

High moisture hay tended to wrap around the large, front rollers on the Vermeer baler; and large slugs of green hay, usually found in the high moisture hay, tended to lodge between these rollers. These two problems increased down time for the Vermeer baler with both grass and lespedeza high moisture hay. With low moisture hay, the Vermeer baler experienced no operational difficulties such as clogging or wrapping of

TABLE 1. Nominal moisture content of hay at baling, September, 1975.

Type Package	Package Number	Day Baled	Time Baled	Percent Moisture Content (Wet Basis)
		Bermudagrass, Cutting No. 2		
High Nominal Moisture Content				
Vermeer Roll	V-15	17[a]	10:50 AM	23.4
Vermeer Roll	V-17	17	11:30 AM	25.3
Hawk Bilt Roll	R-16	17	10:50 AM	24.4
Hawk Bilt Roll	R-19	17	11:00 AM	21.0
Stack	S-15	17	12:00 AM	24.1
Stack	S-16	17	11:45 AM	28.0
Average				24.4
Low Nominal Moisture Content				
Vermeer Roll	V-10	16	5:45 PM	17.4
Vermeer Roll	V-14	16	6:05 PM	18.0
Hawk Bilt Roll	R-12	16	6:00 PM	20.0
Hawk Bilt Roll	R-13	16	6:05 PM	20.2
Stack	S-11	16	6:10 PM	17.7
Stack	S-12	16	7:40 PM	18.0
Average				18.5
		Lespedeza[b]		
High Nominal Moisture Content				
		18	11:30 PM	26.5
		18	11:40 PM	19.2
		18	12:00 PM	21.2
		18	12:15 PM	18.5
Average				21.4
Low Nominal Moisture Content[c]				
		18	1:30 PM	12.3
Average				Less than 12.3

[a]High moisture hay was baled early in the morning before the dew dryed off.

[b]Samples were not taken for individual packages, but were taken randomly throughout the field while baling was in progress.

[c]Only one sample was taken at the low moisture content.

hay around the rollers. Maneuverability of the Vermeer baler was the best of the three machines used, and the operator required only a short time to adapt to the tying and unloading procedure. Some difficulty in starting the rolls was experienced with small windrows. Entering the windrows at an angle with higher than normal ground speed and low power-take-off RPM avoided the difficulty.

The Hawk Bilt baler was not as sensitive to windrow moisture content as the other machines used. Thus, unlike the other machines, the Hawk Bilt did not require a slower ground speed and increased operator attention when baling high moisture hay. The Hawk Bilt baler was the second most difficult machine to operate because of the necessity of keeping the raddle chain speed adjusted to the ground speed of the baler. The baler was large and bulky which made it difficult to maneuver. However, after some experience, the operator could maneuver the machine through most situations with the exception of turning back on an adjacent windrow with a bale in the bale chamber. This baler tended to waste more hay than the Vermeer and Stakhand because of the difficulty in maneuvering and because of hay left behind when a bale neared completion. The Hawk Bilt was simple in design, and had no mechanical breakdowns.

The Stakhand was the most demanding machine to operate because of the requirement of adjusting the canopy to allow equal filling of the stack chamber from front to rear. The Stacker was more sensitive to moisture content than the Hawk Bilt because of decreased capacity of the pickup mechanism as the moisture content increased. The Stakhand was very maneuverable, second only to the Vermeer baler. Operator discomfort

from blowing dust and chaff was a problem with both grass and lespedeza hay, and was especially so with lespedeza hay. Low moisture lespedeza hay produced the most dust and chaff.

II. MACHINE PACKAGING CAPACITIES FOR MIDLAND BERMUDAGRASS AND LESPEDEZA HAYS

A statistically significant difference ($\alpha = 0.01$) in mean capacities of the machines was observed in baling both bermudagrass and lespedeza hays (Table 2). The Hawk Bilt baler had the greatest capacity; the Stakhand had the least. The overall average capacities for the Vermeer, Hawk Bilt and Stakhand were 8.96, 20.60, and 5.17 metric tons (9.88, 22.72, and 5.70 tons), respectively, per hour.

Moisture content also had a significant effect on machine packaging capacity for both the bermudagrass and lespedeza hays (Table 2). The greater packaging capacities observed for the high moisture hay were partially due to the extra water contained in the hay. However, with the exception of the Hawk Bilt baler, the packaging capacities at moisture contents above 25 percent would be expected to decrease because of mechanical limitations of the balers. According to Kilgore (15), the Hawk Bilt baler was used to bale hay at moisture contents up to 47 percent (wet basis) without a drop in total matter packaging capacity.

The degree of significance of moisture content on packaging capacity was greater for lespedeza hay ($\alpha = 0.01$ compared to $\alpha = 0.05$ for bermudagrass). At low moisture content, large numbers of leaves shattered from the lespedeza stems during the packaging operation causing

TABLE 2. Mean packaging capacities of the machines at different moisture levels with Midland bermudagrass and Kobe lespedeza.

Machine	Hay Type	Moisture Content	Packaging Capacity* (Tons/Hr)	(Metric Tons/Hr)
Vermeer	Bermudagrass	High	14.3^{bc}	13.0^{bc}
Hawk Bilt	Bermudagrass	High	28.2^{a}	25.6^{a}
Stacker	Bermudagrass	High	7.8^{c}	7.1^{c}
Vermeer	Bermudagrass	Low	10.5^{c}	9.5^{c}
Hawk Bilt	Bermudagrass	Low	21.9^{ab}	19.9^{ab}
Stacker	Bermudagrass	Low	6.1^{c}	5.5^{c}
Vermeer	Bermudagrass	Both	12.4^{a}	11.3^{a}
Hawk Bilt	Bermudagrass	Both	25.1^{b}	22.7^{b}
Stacker	Bermudagrass	Both	6.9^{c}	6.3^{c}
All	Bermudagrass	High	16.8^{a}	15.2^{a}
All	Bermudagrass	Low	12.9^{b}	11.7^{b}
Vermeer	Lespedeza	High	7.0^{b}	6.3^{b}
Hawk Bilt	Lespedeza	High	32.2^{a}	29.2^{a}
Stacker	Lespedeza	High	6.0^{b}	5.4^{b}
Vermeer	Lespedeza	Low	7.6^{b}	6.9^{b}
Haw Bilt	Lespedeza	Low	8.5^{b}	7.7^{b}
Stacker	Lespedeza	Low	2.9^{c}	2.6^{c}
Vermeer	Lespedeza	Both	7.3^{a}	6.6^{a}
Hawk Bilt	Lespedeza	Both	20.4^{b}	18.5^{b}
Stacker	Lespedeza	Both	4.4^{c}	4.0^{c}
All	Lespedeza	High	15.1^{a}	13.6^{a}
All	Lespedeza	Low	6.3^{b}	5.8^{b}
Vermeer	Both	Both	9.9^{a}	9.0^{a}
Hawk Bilt	Both	Both	22.7^{b}	20.6^{b}
Stacker	Both	Both	5.7^{c}	5.2^{c}
All	Both	High	15.9^{a}	14.4^{a}
All	Both	Low	9.6^{b}	8.7^{b}
All	Bermudagrass	Both	14.8^{a}	13.4^{a}
All	Lespedeza	Both	10.7^{b}	9.7^{b}

*Means within each category having similar superscripts are not significantly different at $\alpha = 0.05$.

lower capacities. Characteristics of the grass hay were affected less by moisture content.

A significant interaction between machines and moisture content of lespedeza hay is shown by the analysis of variance for packaging capacity (Table 6, Appendix). This interaction may be explained by the extremely long windrows of high moisture hay baled and the short, dry windrows of low moisture hay baled. The moisture content was less than 12.3 percent for the low moisture observations. The dry, fluffy hay decreased packaging capacity. The long windrows of high moisture hay were ideal for the Hawk Bilt baler because few short turns were required and the machine readily baled high moisture hay. Likewise baling the low moisture hay in short windrows was detrimental to the packaging capacity of this machine. The stacker also had an extremely low packaging capacity of 2.63 metric tons (2.90 tons) per hour in the low moisture lespedeza baling test (Table 2). This low capacity was attributed to lack of operator skill. Different operators performed the high and low moisture trials. These low capacity problems were not present in the bermudagrass tests, hence the treatment by moisture interaction was not significant for this material.

Overall mean packaging capacity, averaged over all of the machines, was significantly higher for bermudagrass than for lespedeza (Table 2). This difference was due to the fluffy condition of the lespedeza hay and the lower yield from the lespedeza field. The lespedeza field yielded approximately 0.65 metric tons per hectare (1.7 tons per acre) and the bermudagrass field approximately 0.85 metric tons per hectare (2.3 tons per acre).

III. HANDLING CHARACTERISTICS AND CAPACITIES WITH THE LARGE HAY PACKAGES

Certain physical characteristics such as stability and shape were very important to efficient handling of the large hay packages. The packages were allowed to settle for at least 24 hours, in some cases for 72 hours, in the hay field before being moved. The longer settling period proved very desirable for package stability especially with the bermudagrass packages.

The lespedeza packages were much more stable and retained their shape better than the bermudagrass ones. These favorable characteristics were attributed to steminess and intertwining of the lespedeza foliage within the package. The bermudagrass foliage remained smooth and slippery which allowed layers of grass to slide across each other. The difference in stability between bermudagrass and lespedeza packages was especially apparent in the stacks and Hawk Bilt bales. The baler twine wrapped around the Vermeer rolls kept them intact. Sluffing of hay from the Hawk Bilt rolls when they were being moved from the fields was greater than for the Vermeer and Stakhand packages. When moving the lespedeza hay, noticeably fewer incidents of stacks falling over and of hay sluffing from the Hawk Bilt rolls were recorded.

No difference was detected in the handling capacities for the three types of bermudagrass packages (Table 3). However, the handling capacity for the lespedeza stacks was significantly greater than for the other two package types. This greater handling capacity for lespedeza stacks can be attributed to ability of the operators to drive faster with less caution than with the less stable bermudagrass stacks.

ABLE 3. Handling capacity means for different package and hay types.

achine	Hay Type	Moisture Content	Handling Capacity* (Tons/Hr)	(Metric Tons/Hr)
ermeer	Bermudagrass	Both	12.7	11.5
awk Bilt	Bermudagrass	Both	13.3	12.1
tacker	Bermudagrass	Both	13.8	12.5
11	Bermudagrass	High	12.3	11.2
11	Bermudagrass	Low	14.2	12.9
ermeer	Lespedeza	Both	11.7^{a}	10.6^{a}
awk Bilt	Lespedeza	Both	10.5^{a}	9.6^{a}
tacker	Lespedeza	Both	15.5^{b}	14.1^{b}
11	Lespedeza	High	13.8^{a}	12.5^{a}
11	Lespedeza	Low	11.4^{b}	10.4^{b}
ermeer	Bermudagrass	Both	12.7^{abc}	11.5^{abc}
awk Bilt	Bermudagrass	Both	13.3^{abc}	12.1^{abc}
tacker	Bermudagrass	Both	13.8^{bc}	12.5^{bc}
ermeer	Lespedeza	Both	11.7^{ab}	10.6^{ab}
awk Bilt	Lespedeza	Both	10.5^{a}	9.5^{a}
Stacker	Lespedeza	Both	15.5^{c}	14.1^{c}
Vermeer	Both	Both	12.2^{a}	11.1^{a}
Hawk Bilt	Both	Both	11.9^{a}	10.8^{a}
Stacker	Both	Both	14.7^{b}	13.3^{b}
All	Bermudagrass	Both	13.3	12.0
All	Lespedeza	Both	12.6	11.4
All	Both	High	13.0	11.8
All	Both	Low	12.8	11.6

*Means within each category having similar or no superscripts are not significantly different at $\alpha = 0.05$.

A significant difference was expected in the handling capacities for stacks of both bermudagrass and lespedeza hay as compared to that for roll bales because of the large size of the stacks. The packages were moved individually; therefore, theoretically the larger packages should have a higher handling capacity. Table 3 indicates no difference in the mean handling capacities of the bermudagrass packages, and this is a result of slower ground speeds and the necessary careful handling of the bermudagrass stacks.

The overall mean handling capacities for lespedeza packages at high and low moisture contents were respectively 12.47 metric tons (13.75 tons) and 10.35 metric tons (11.42 tons) per hour. These capacities were significantly different (Table 3) because of greater density of the high moisture lespedeza hay (Table 4).

The overall means comparing handling capacities for bermudagrass and lespedeza hays (Table 3) were 12.04 metric tons (13.28 tons) and 11.41 metric tons (12.58 tons) per hour, respectively. Overall means comparing handling capacities for high and low moisture content were 11.83 metric tons (13.04 tons) and 11.63 metric tons (12.83 tons) per hour, respectively. Neither hay type nor moisture content had a significant effect on overall handling capacity ($\alpha = 0.05$).

IV. STORAGE OF LARGE PACKAGES OF MIDLAND BERMUDAGRASS AND LESPEDEZA HAYS

Temperatures rise inside hay packages at the beginning of the storage period because of micro-organism activity on the plant material. During the curing process, excess water vapor and heat are removed by

TABLE 4. Mean density of the hay packages for bermudagrass and lespedeza at two moisture levels.

Package Type	Hay Type	Moisture Content	Density* (Lbs/Ft^3)	Density* (Kg/M^3)
Bermeer	Bermudagrass	Both	9.5^{a}	152^{a}
Hawk Bilt	Bermudagrass	Both	5.7^{b}	91^{b}
Stacker	Bermudagrass	Both	4.9^{b}	79^{b}
All	Bermudagrass	High	6.6	106
All	Bermudagrass	Low	6.8	108
Vermeer	Lespedeza	Both	7.7^{a}	124^{a}
Hawk Bilt	Lespedeza	Both	6.4^{b}	103^{b}
Stacker	Lespedeza	Both	4.8^{c}	77^{c}
All	Lespedeza	High	6.6^{a}	106^{a}
All	Lespedeza	Low	6.1^{b}	97^{b}
Vermeer	Bermudagrass	Both	9.5^{a}	152^{a}
Hawk Bilt	Bermudagrass	Both	5.7^{cd}	91^{cd}
Stacker	Bermudagrass	Both	4.9^{d}	69^{d}
Vermeer	Lespedeza	Both	7.6^{b}	124^{b}
Hawk Bilt	Lespedeza	Both	6.4^{c}	103^{c}
Stacker	Lespedeza	Both	4.8^{d}	77^{d}
Vermeer	Both	Both	8.6^{a}	138^{a}
Hawk Bilt	Both	Both	6.1^{b}	97^{b}
Stacker	Both	Both	4.9^{c}	78^{c}
All	Bermudagrass	Both	6.7	107
All	Lespedeza	Both	6.3	101.60

*Means within each category having similar or no superscripts are not significantly different at $\alpha = 0.05$.

convective air currents within the package. As the hay reaches an equilibrium moisture content, the micro-organism activity stops; and the package temperature approaches ambient air temperature, denoting completion of the curing process.

The temperatures of high moisture Vermeer, Hawk Bilt and Stakhand packages are presented in Figure 9. The Vermeer packages had continuously higher temperatures than other packages which may be attributed to significantly higher package density (Table 4). The densely packed hay restricts air circulation within the package for drying and cooling. A direct correlation was noted between curing temperature and package density. The stacks had the lowest temperatures throughout the curing period because of low density and "layered" construction. Air could pass through the flat layers of grass easier than through rolled layers of the Hawk Bilt and Vermeer bales. Inspection of Figure 9 reveals an obvious effect of ambient air temperature changes on packaging temperatures during curing. The distinct fluctuation of temperatures within the Hawk Bilt and Stakhand packages, which correspond with dramatic ambient air temperature changes, indicate better air circulation within the less dense packages.

A lower temperature within low moisture packages was expected because of less microbiological activity found by Miller (18) at low moisture levels. Figure 10 supports this expectation. It shows a constantly higher temperature for the high moisture lespedeza. The low moisture hay reached an equilibrium moisture content sooner also. With reduction in moisture content, greater concentration of plant sugars and salts occurs in the forage materials which halts the microbiological

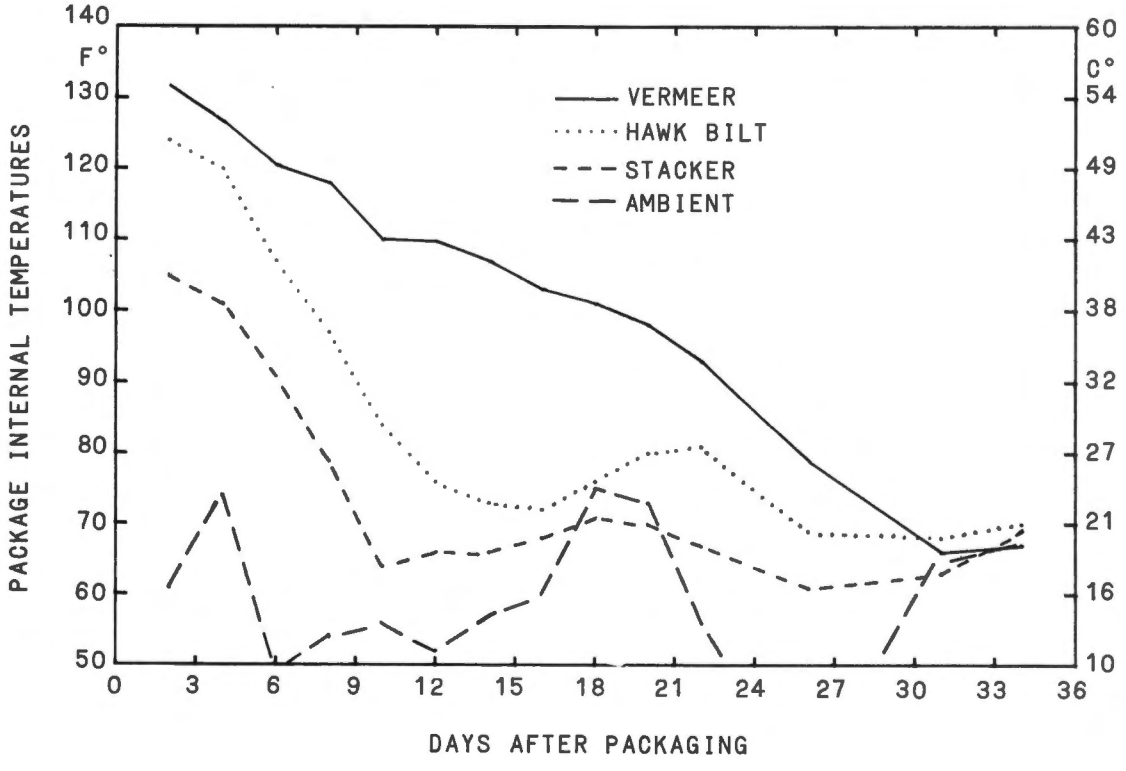

FIGURE 9. Mean curing temperatures for the three package types of both bermudagrass and lespedeza high moisture hays.

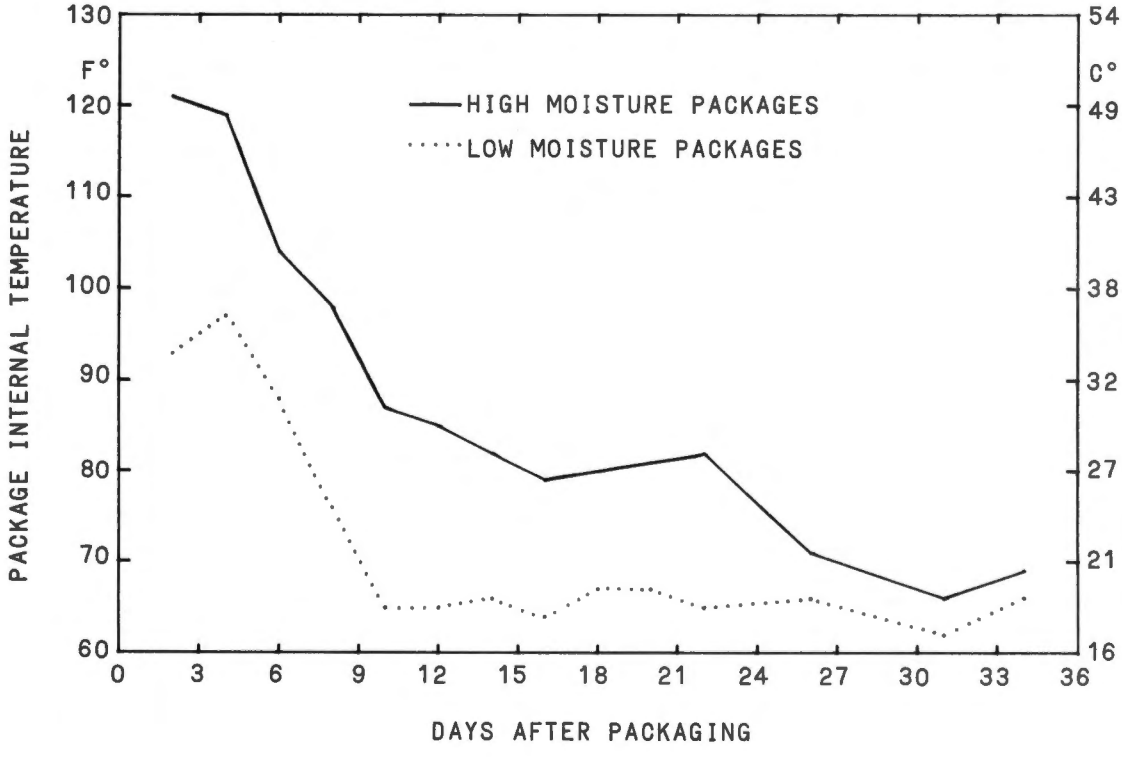

FIGURE 10. Curing temperatures of high and low moisture lespedeza hays.

action (18). Without heat of respiration to dissipate, the packages remained at lower temperatures.

The greater nutrient content of the lespedeza hay would suggest a higher curing temperature than that of bermudagrass hay because of more plant nutrients subject to initial micro-organism attack. However, Figure 11 shows similar temperatures for both bermudagrass and lespedeza packages. Possibly more air circulated through the lespedeza bales due to the steminess and physical makeup of the plants. This extra circulation perhaps removed heat of respiration at a rate to cause the temperature of the lespedeza packages to be about the same as that of bermudagrass packages.

The temperature graph (Figure 12) comparing inside and outside storage indicates a slight cooling effect from the air circulation available to packages stored outside.

Color and odor ratings were made by the Plant and Soil Science Department for core samples taken at the beginning and end of the storage period. The mean scores of these ratings are presented in Table 5. Because of the manner of rating the samples, the bermudagrass and lespedeza ratings are not comparable. Of all lespedeza packages stored outside, the Vermeer packages had better color and odor ratings. This could be explained by the significantly greater density of the Vermeer bales (Table 4, page 43). No definite trend in color and odor ratings was detected among the three types of packages of bermudagrass hay. However, inside stored packages had better ratings than outside stored packages, for both hay types, with the exception of high moisture lespedeza. The less desirable color and odor ratings for the high

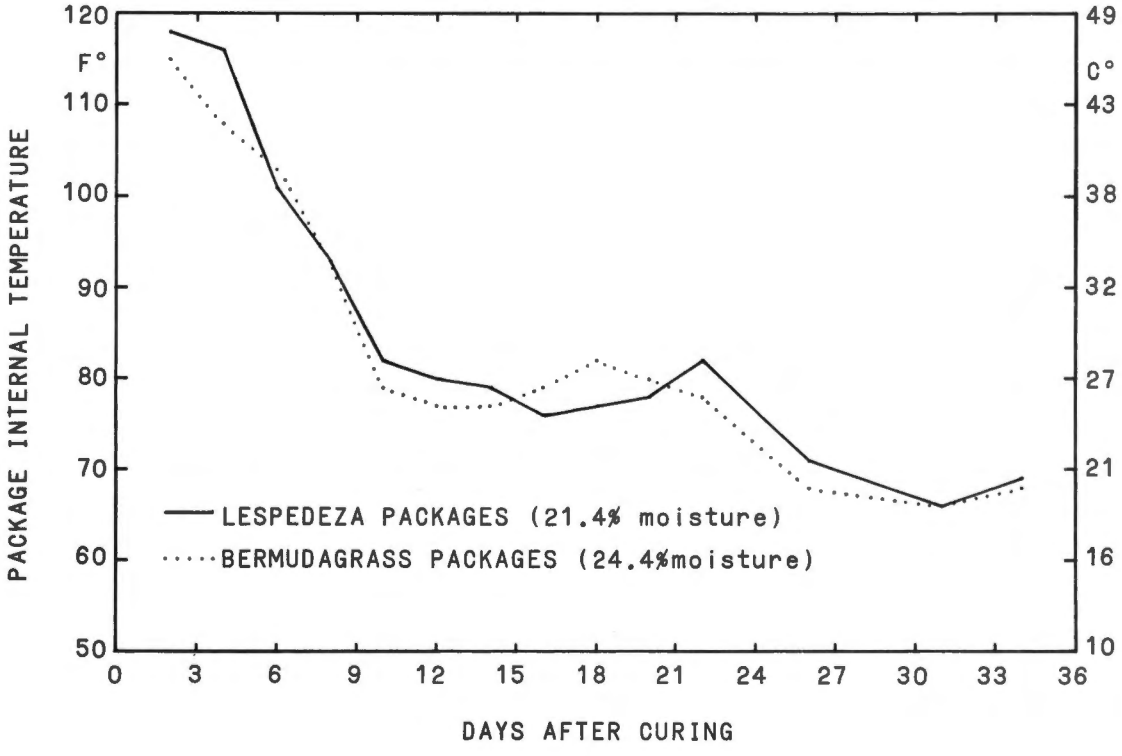

FIGURE 11. Curing temperatures of bermudagrass and lespedeza hays having high moisture contents with inside and outside storage.

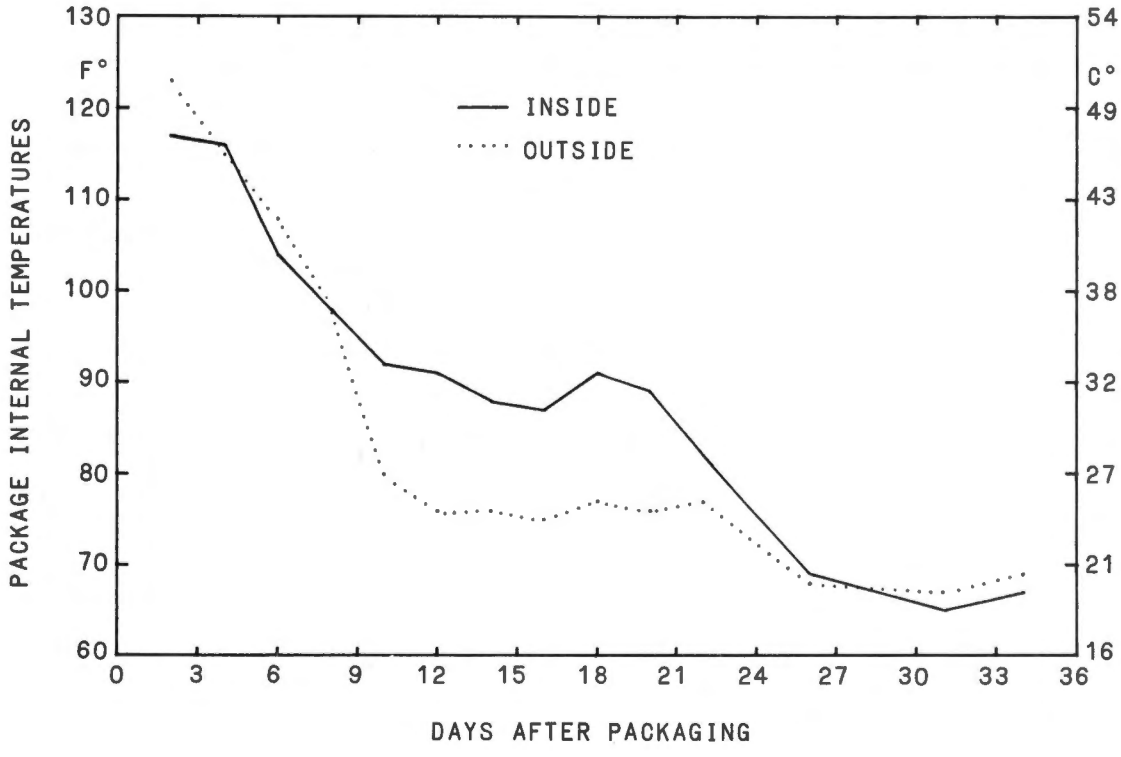

FIGURE 12. Curing temperatures of inside and outside storage hays of high moisture content and all package types.

TABLE 5. Color and odor ratings for core samples taken from bermudagrass and lespedeza hay packages.

Bale Type	Moisture Content	Storage Conditions[d]	Color[a]	Odor[b]
		Bermudagrass		
All	High		1.67	1.45
Vermeer	High	Outside	2.33	1.60
Hawk Bilt	High	Outside	3.33	2.33
Stacker	High	Outside	2.75	2.00
Vermeer	High	Inside	3.00	1.50
Hawk Bilt	High	Inside	2.50	2.50
Stacker	High	Inside	1.50	1.50
All	Low		1.92	1.57
Vermeer	Low	Outside	3.33	2.83
Hawk Bilt	Low	Outside	2.33	1.6]
Stacker	Low	Outside	2.00	2.50
Vermeer	Low	Inside	2.50	1.20
Hawk Bilt	Low	Inside	3.50	2.50
Stacker	Low	Inside	2.00	1.50
		Lespedeza		
All	High		2.33	2.67
Vermeer	High	Outside	3.17	2.67
Hawk Bilt	High	Outside	3.50	3.75
Stacker	High	Outside	3.33	3.17
Vermeer	High	Inside	4.00	3.50
Hawk Bilt	High	Inside	3.50	3.75
Stacker	High	Inside	3.33	3.17
All	Low		1.87	2.45
Vermeer	Low	Outside	2.83	3.33
Hawk Bilt	Low	Outside	2.50	2.60
Stacker	Low	Outside	2.92	3.00
Vermeer	Low	Inside	3.50	4.00
Hawk Bilt	Low	Inside	2.00	1.20
Stacker	Low	Inside	3.00	3.50

[a]Used a range of 1 to 4 with the following meaning: (1) light green, (2) olive green, (3) yellow to light brown, and (4) brown to black.

[b]Used a range of 1 to 4 with the following meaning: (1) light and pleasant, (2) dusty, (3) slightly musty, and (4) musty.

[c]Average ratings for all packages at the beginning of storage.

[d]Type of storage used for a three-month period.

moisture lespedeza. The less desirable color and odor ratings for the high moisture lespedeza may have been caused from lack of air circulation needed for moisture removal. Note that the samples were frozen for six months before the ratings were made, making possible the deterioration of samples.

The average depths of spoilage for both types of hay stored outside in Vermeer, Hawk Bilt and Stakhand packages are presented in Figure 13. The spoilage depths of bermudagrass and lespedeza hay packages show that water did not penetrate the thatched covering of the bermudagrass packages as readily as the outer layers of lespedeza. A comparison of the densities of the three types of bermudagrass and lespedeza packages (Table 4, page 43) with the spoilage depths in Figure 13 indicates a relationship of density to depth of water penetration. The Vermeer bale had a density for bermudagrass of 152.3 kilograms per cubic meter (9.50 lbs/ft^3) which is significantly higher ($\alpha = 0.05$) than densities of 90.8 and 79.1 kilograms per cubic meter (5.67 and 4.93 lbs/ft^3) for Hawk Bilt and Stakhand bermudagrass packages. Figure 13 depicts moisture penetration of 6.8 centimeters (2.86 in) for the bermudagrass Vermeer bale versus penetrations of 9.5 and 10.0 centimeters (3.75 and 3.95 in) for the Hawk Bilt and Stakhand packages, respectively. The densities for lespedeza packages were significantly different for all three machines; and as expected, there were equally large differences in the depth of spoilage found between each of the packages. Again, package density affected the depth of spoilage. The density did not affect spoilage depths of bermudagrass packages as much as lespedeza packages. This difference occurred because lespedeza does not

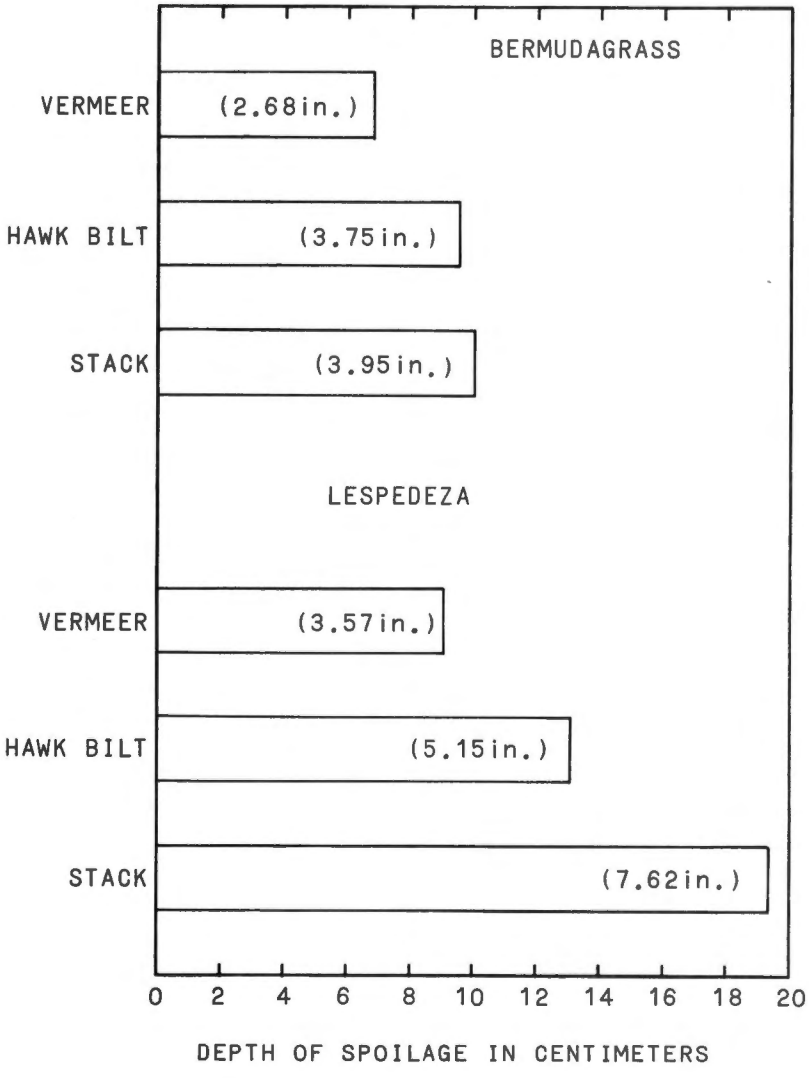

FIGURE 13. Average depth of hay spoilage for the three types of hay packages with bermudagrass and lespedeza hay.

readily form a thatched covering such as that found on bermudagrass packages.

V. FEEDING LARGE PACKAGES OF BERMUDAGRASS AND LESPEDEZA HAYS

The feeding trials were conducted in December, 1974, and frequent rains left the ground surrounding the feeders muddy during most of the four weeks of the trials. The feeders were resting on timbers which held the floors off the ground 10 to 15 centimeters (4 to 6 in). This space kept the mud and water away from the hay packages. Although the feeders remained in the same position for the entire feeding trials, the mud did not get sufficiently deep enough to hinder cattle access to the hay. The floor of each feeder provided a firm resting place for the cattle's front feet of the cattle after the sliding gates were pushed toward the center of the feeder from the floor edge. The roofs on the feeders kept the hay dry and provided desirable eating conditions during the rainy weather. When wet hay packages were placed in the feeders, they dried to some extent and the cattle accepted more of the outer, covering layer of hay.

The waste from hay being pulled out of the feeders and trampled into the ground was low. Observation of hay buildup around the feeders each week indicated losses of less than 5 percent of the hay packages. There seemed to be slightly more buildup around feeders containing stacks, which may be attributed to the low density of the stacks and consequent ease of pulling hay from the packages. The slanted boards on the gates were effective in keeping the cattle from backing

out of the feeders while they were eating.

Generally the sliding gates worked well. The runners were greased each week to decrease the change of a gate sticking. Only one gate stuck in a manner that may have affected the feeding trials, and this was during the last week of feeding. Because of the muddy conditions, two men were required to remove and reinstall the gates each time the feeders were filled with hay.

For the first week of the feeding trials, two roll bales were put into each feeder designated for roll bales. After two days it was obvious these feeders were not working properly with two rolls, so one of the rolls was removed from each feeder. All of the roll bales were initially placed in the feeders with the long axis perpendicular to the gates as shown in Figure 14. Figure 15 shows the cumulative consumption of the hay packages as the week progressed. The analysis of variance for percentage consumption of hay packages (Table 9, Appendix) indicates a significant difference ($\alpha = 0.01$) for package type (treatment) and also a difference in the amount of hay consumed on successive days. Bermudagrass was fed the first week. During this period, stacks were the most preferred package types with the Hawk Bilt rolls nearly as acceptable to the animals. The Vermeer rolls were not consumed as readily by the animals because of difficulty the cattle experienced in pulling hay from the ends of the bales. The grass had been rolled around the core of the bale to form a dense package. The hay in these dense packages was not easily pulled from the ends of the bales. The cattle finally quit trying to eat the Vermeer bales, even though the hay quality was acceptable.

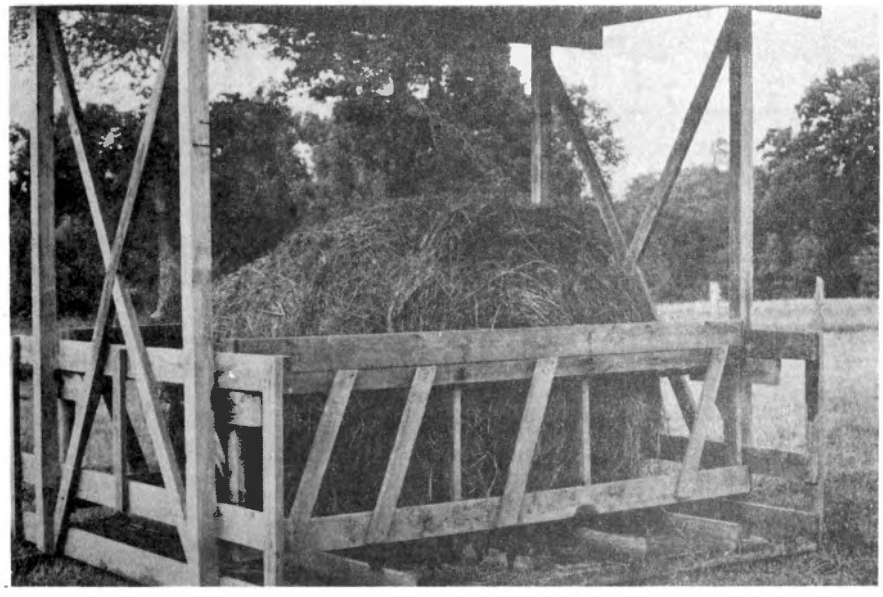

FIGURE 14. Vermeer bale improperly placed in the feeder.

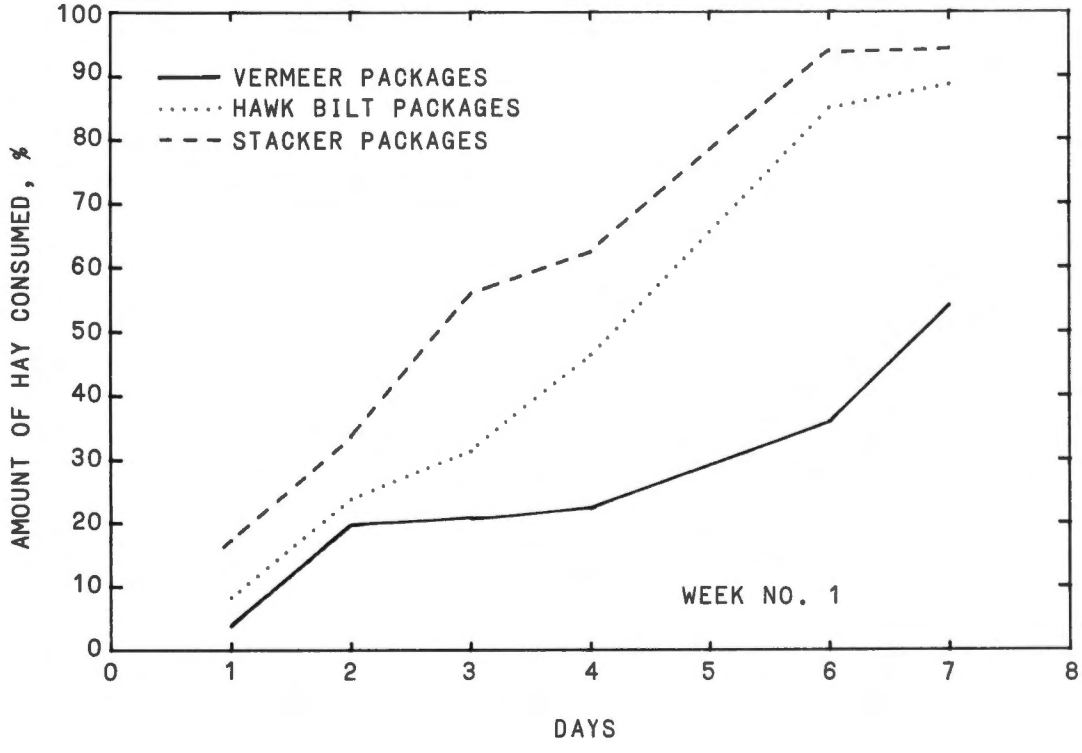

FIGURE 15. Cumulative consumption of low moisture bermudagrass packages stored outside with the Vermeer bales positioned on their side.

The significant interaction of treatments by days shown in Table 9, Appendix, can be explained by Figure 15. Note the increased consumption of the Vermeer bales after the Hawk Bilt and Stakhand packages had been consumed.

Figure 16 shows the cumulative consumption of bermudagrass hay during the second week of the feeding trials. In this test, the Vermeer bales were placed on their ends with the central axes perpendicular to the ground (Figure 17). The analysis of variance (Table 9, Appendix) indicates no difference in the percentages of hay consumed from each package type (Treatment). There was a significant difference in the consumption of hay on different days. Because the different type packages were eaten at the same rate (Figure 16), interaction between days and treatments was not significant. A comparison if Figures 15 and 16 shows that cattle preferred the Vermeer bale positioned on end. This position allowed the hay to flake off the bale core for easier access. Figure 18 indicates no great difference in the amount of hay the cattle refused to eat from each type of bermudagrass packages.

Lespedeza packages were used for the third week of feeding. The analysis of variance for cumulative hay consumption (Table 9, Appendix) shows a significant difference ($\alpha = 0.05$) among bale types (Treatment). Figure 19 illustrates that Hawk Bilt packages were the least preferred and that Vermeer bales were the most preferred. The treatment by day interaction was significant ($\alpha = 0.05$), and was considered to be the result of the Hawk Bilt packages being shunned by cattle until after the Vermeer and Stakhand packages had been consumed. Figure 18 indicates a large amount of waste for the Hawk Bilt bales and a lesser

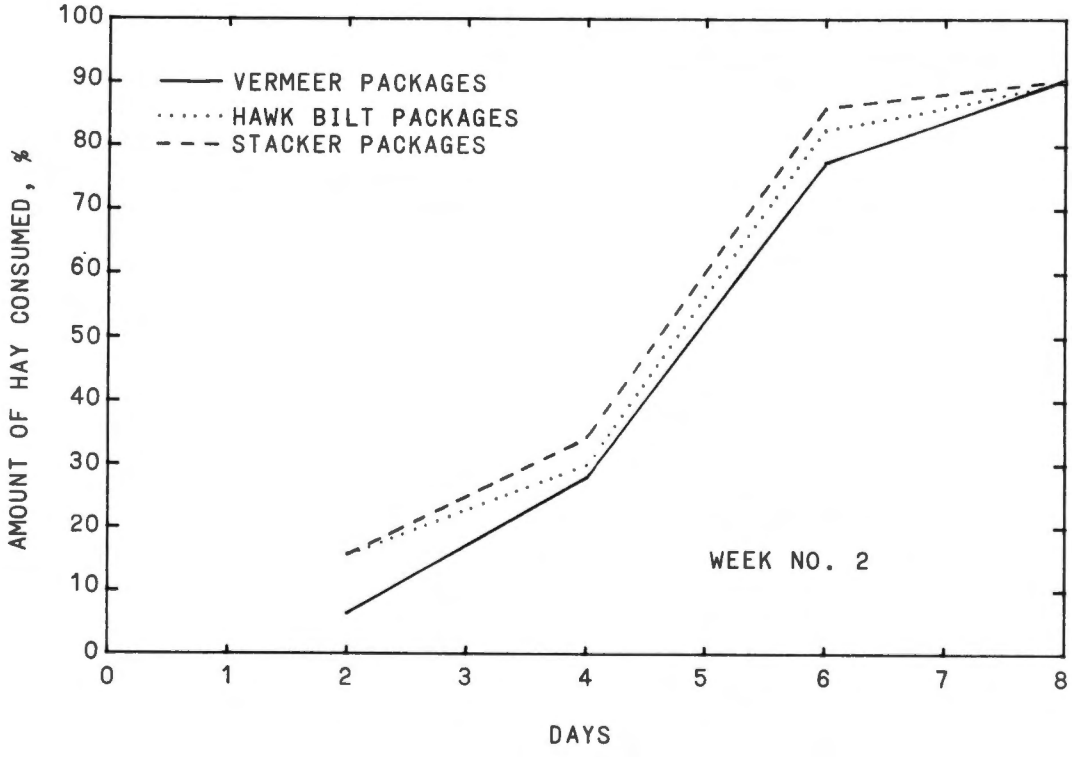

FIGURE 16. Cumulative consumption of high moisture bermudagrass packages stored outside with the Vermeer bales positioned on end.

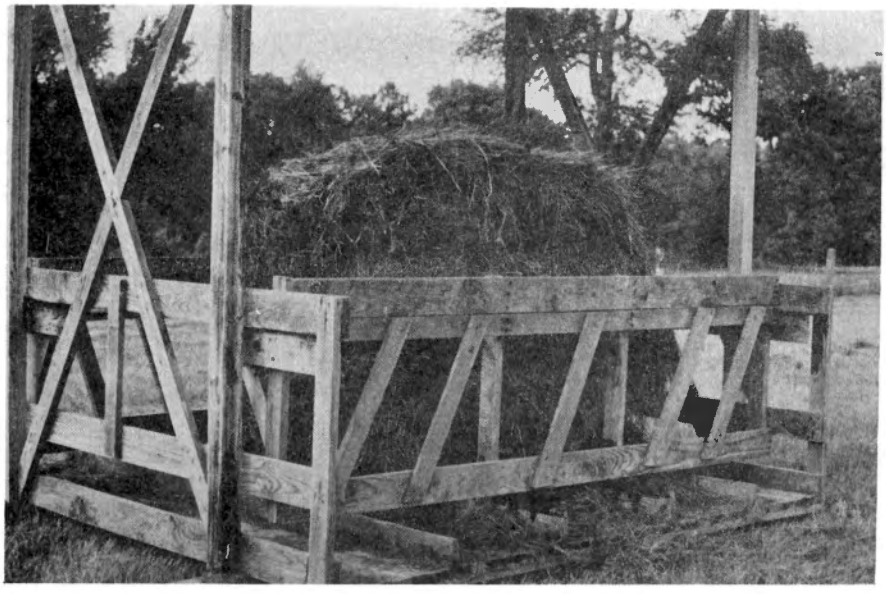

FIGURE 17. Vermeer bale properly positioned in the feeder.

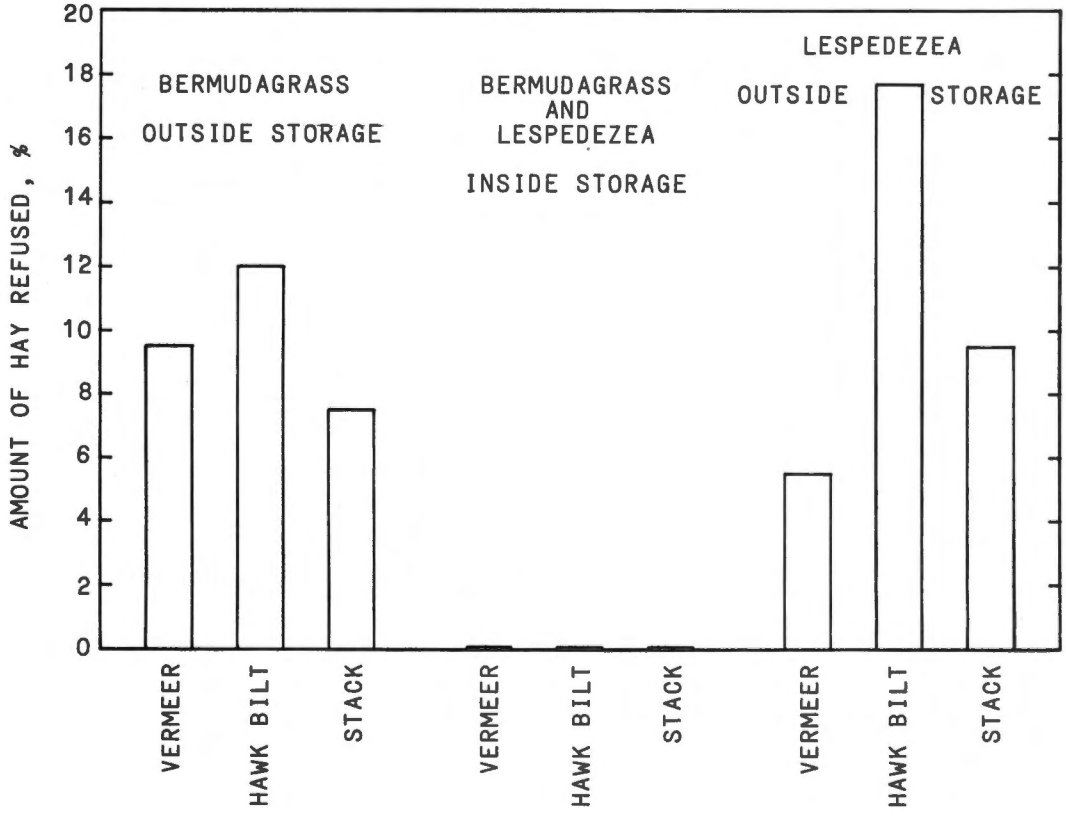

FIGURE 18. Percentage of hay refused when fed in sliding gate feeders.

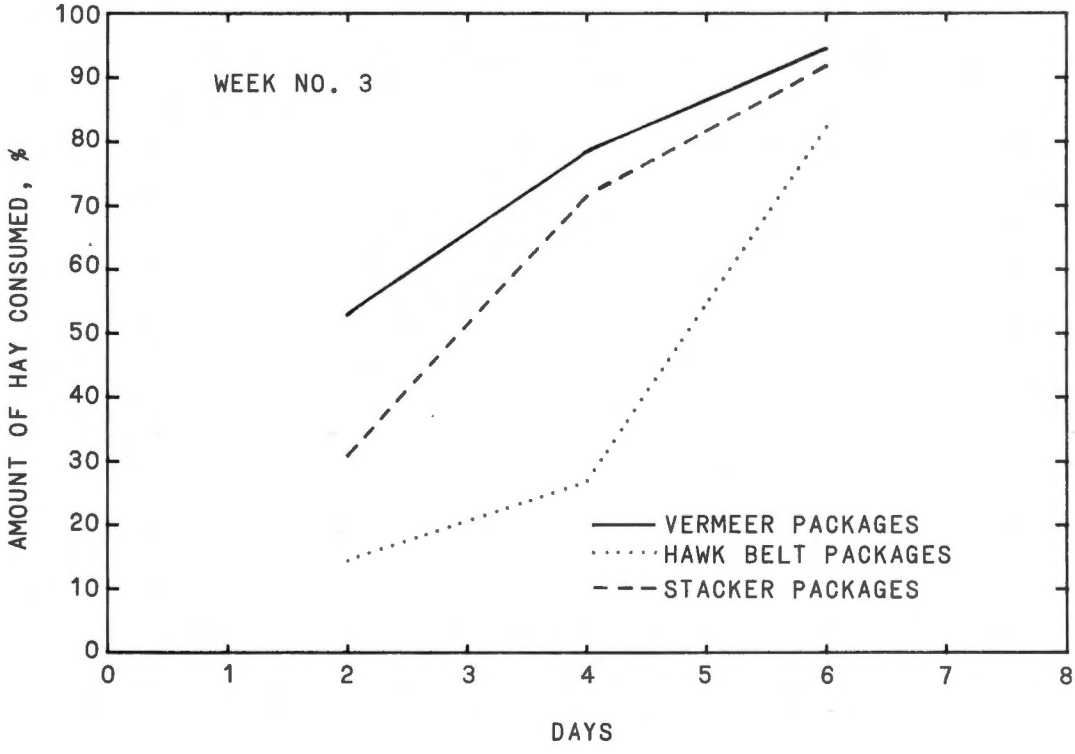

FIGURE 19. Cumulative consumption of lespedeza packages stored outside.

amount for the stacks. The amount of waste coupled with the acceptance data suggests a greater amount of decayed lespedeza hay associated with the Hawk Bilt and Stakhand packages than with the Vermeer bales. As shown in Figure 13, page 52, the Vermeer bale had a lower depth of spoilage than the other two types of packages. However, the Hawk Bilt bales were lower in depth of spoilage than stacks; yet, the waste was higher for the Hawk Bilt bales. This observation may be explained by noting the smaller size of the Hawk Bilt bale as compared to the stacks. The stacks had a lower surface to volume ratio. This would allow a larger relative percentage of the Hawk Bilt bales to be exposed to the atmosphere as compared to Stakhand packages.

During the fourth week cattle were fed hay packages that had been stored inside. Day of feeding was the only variable affecting cumulative consumption significantly during this feeding period (Table 9, Appendix). This would indicate that when no deterioration factors were involved, the cattle had no preference between packages. Note that Vermeer bales were placed on end for every weekly test except the first.

The cattle were expected to prefer inside stored hay over outside stored, and lespedeza hay over bermudagrass. These preferences were expected because of the higher quality of lespedeza and inside stored hay. Comparison of Figures 15, 16, and 19 (pages 56, 58, and 61, respectively), and Figure 20 shows that cattle ate the outside stored bermudagrass hay in 7.5 days, the outside stored lespedeza hay in 6 days, and both inside storage hays in 5 days. Thus the expected preferences were substantiated.

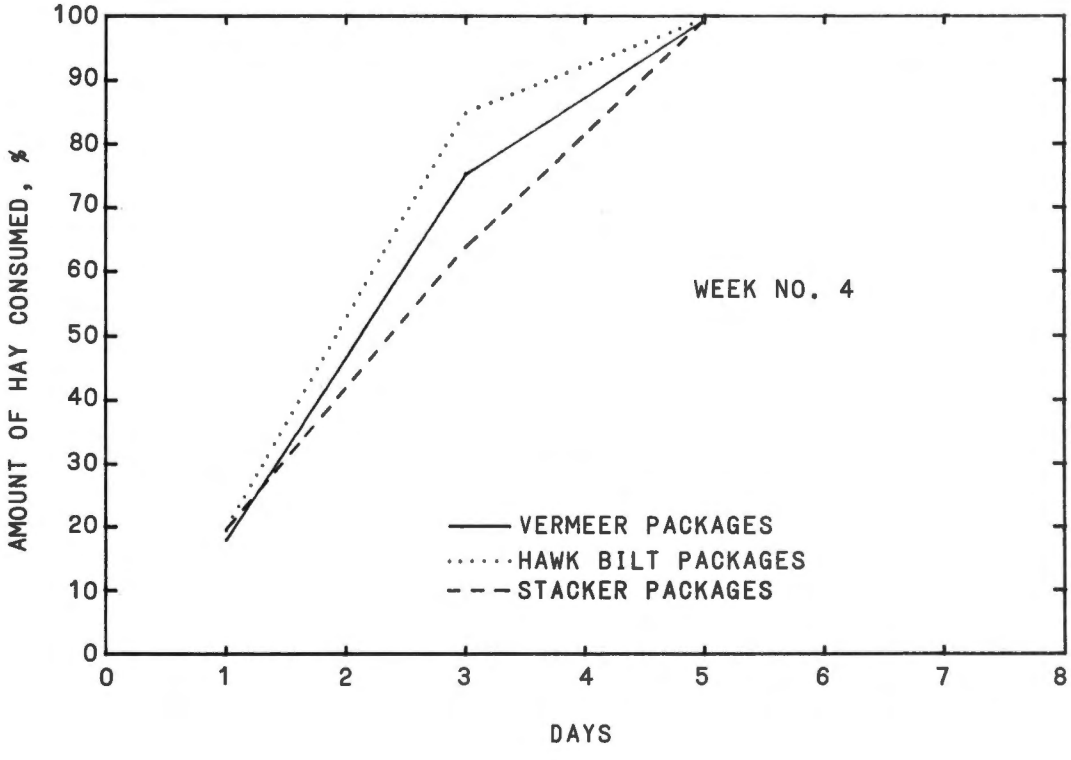

FIGURE 20. Cumulative consumption of bermudagrass and lespedeza packages stored inside.

The cattle seemed to prefer the less dense stacks to the Hawk Bilt and Vermeer packages when no excessive spoilage factors were involved, as with the lespedeza packages. Figure 20 does not indicate the preference for stacks, but the preference curve for stacks in this figure could be erroneous because of a stuck gate found on a stack feeder during the third day of the test. Cattle normally prefer to eat where food is easiest to obtain, and the hay was easiest to pull from the low density stacks. The hay toward the centers of the stacks seemed fresher and of a higher quality than the musty hay found near the centers of the more dense Vermeer bales.

The amounts of hay left in the feeders at the ends of the various feeding tests are shown in Figure 18, page 60. The difference between hay left from the inside storage test and that left from the bermuda-grass and lespedeza packages stored outside is an indicator of the amount of hay lost when hay packages are stored outside. The difference in amount of hay refused varied from 4 to 17 percent of initial package weights. The density of the Vermeer bale was effective in reducing the wastes from decay in the lespedeza packages. However, the wastes from bermudagrass packages were more equal because of smaller differences in the depth of spoilage (Figure 13, page 52). These results suggest that high density packages are best for leguminous hay but not for grass hays.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The objective of this study was to evaluate the baling, handling, storage, and feeding differences between grass and leguminous hay baled with large-package machines. Each type of hay was packaged at two moisture levels, the bermudagrass hay at nominal moisture contents of 24.4 and 18.5 percent (wet basis), and the lespedeza hay at nominal moisture contents of 21.4 and 12.3 percent (wet basis). Packaging capacities were calculated from field operating data taken for Vermeer, Hawk Bilt and Stakhand machines used to package the hay. Handling capacity and density were determined for each type of hay package. Curing temperatures and spoilage depth data were taken for representative packages of each treatment. Both inside and outside storage were used with a representative package from each treatment stored inside. Core samples were taken at the beginning and end of a three-month storage period. Feeding tests, using sliding gate feeders, were conducted at the end of the storage period to determine cattle preference among package types and the amount of hay refused for each package type.

The Hawk Bilt baler had the greatest packaging capacity, with the Vermeer and Stakhand ranking second and third. When packaging the hay, the Vermeer baler was most sensitive to hay moisture content and the Hawk Bilt was the least sensitive to moisture content. The packaging

capacity of the machines was greater for bermudagrass than for lespedeza.

The lespedeza packages were more stable than bermudagrass packages during transport. The handling capacity of lespedeza stacks was greater than any of the other packages. The high moisture lespedeza packages had greater handling capacity because package density was significantly higher than the low moisture lespedeza packages. No significant difference was detected in the handling capacities for bermudagrass packages. Curing temperatures reached hotter values for the high moisture packages, but no difference was evident between the curing temperatures of the bermudagrass and lespedeza bales. Density affected the curing temperatures since the greater density Vermeer bales had a higher curing temperature than the Hawk Bilt or Stakhand packages.

The depth of spoilage was greatest on the lespedeza stacks. Density was a major determining factor in the depth of water penetration into the hay packages. This was especially true for the lespedeza packages. Density had less effect on water penetration for the bermudagrass packages because of the thatched covering formed over the grass bales. Depth of spoilage was less for Vermeer bales of both bermudagrass and lespedeza hays.

Color and odor ratings were better for inside storage packages with the exception of high moisture lespedeza.

Vermeer bales were more readily eaten by cattle when placed in the feeders with the cylindrical axis perpendicular to the ground. When bermudagrass was fed, there was no great difference in package type preference. However, the cattle definitely preferred the lespedeza

in Vermeer bales rather than in Hawk Bilt and Stakhand packages. The packages stored inside were consumed quicker, with no hay refused from these bales. The amount of lespedeza hay refused was greatest with Hawk Bilt bales and least for Vermeer bales. Little difference was found between package type in the amount of bermudagrass hay refused. The estimated waste outside the feeders was below 5 percent.

II. CONCLUSIONS

1. The depth of spoilage in hay packages stored outside was greatest for the lespedeza stacks. The spoilage depth appeared to be inversely related to the density of the packages. Spoilage depth was least for the Vermeer packages of both bermudagrass and lespedeza hays. All bermudagrass packages had a lower spoilage depth than similar lespedeza packages.

2. Vermeer bales were more readily eaten by cattle when positioned on end with the central axis perpendicular to the ground. Cattle generally preferred the lower density stacks to the Hawk Bilt and Vermeer packages, except with lespedeza hay stored outside. When lespedeza hay was fed, the cattle preferred the Vermeer packages. Cattle also preferred inside stored hay of both types.

3. When lespedeza hay stored outside was fed, more hay was refused from the Hawk Bilt packages (17.0 percent) than the Vermeer or Stakhand packages (5.5 and 9.5 percent). No difference was found among the amounts refused from bermudagrass packages stored outside. There was no refusal of the hay stored inside.

4. The waste from hay pulled outside the sliding gate feeders and trampled into the mud was less than 5 percent.

5. The packaging capacity for the Hawk Bilt baler was greater than the Vermeer, and the packaging capacity of the Vermeer baler was greater than that of the Stakhand. The Hawk Bilt baler was also less sensitive to hay moisture content than either the Vermeer or Stakhand machines.

6. The Vermeer packages were the most dense (138.28 kg/m^3 or 8.63 lbs/ft^3) followed by Hawk Bilt packages (96.94 kg/m^3 or 6.05 lbs/ft^3) and Stakhand packages (78.26 kg/m^3 or 4.88 lbs/ft^3).

7. The Vermeer bales had the highest curring temperatures; stacks had the lowest. These temperature differences were attributed to the densities of the packages.

8. The high moisture packages had consistently higher curring temperatures; there was no significant difference in the curring temperatures of the bermudagrass and lespedeza packages.

9. Lespedeza packages were more stable than bermudagrass packages; handling capacities for lespedeza stacks were greater than for other package types.

10. The Vermeer baler was the most maneuverable machine, while the Hawk Bilt was the least maneuverable because of its bulkiness and long turning radius.

11. Packaging capacities were greatest for high moisture hay both for bermudagrass and lespedeza. Packaging capacities were greater for bermudagrass than lespedeza hay.

12. Color and odor ratings were generally best for high and low moisture, inside stored bermudagrass packages and for low moisture lespedeza packages stored inside.

III. RECOMMENDATIONS FOR FURTHER STUDY

Difficulties encountered in obtaining sufficient differences in moisture content would suggest a greater difference in packaging moisture contents. This would allow more time for obtaining the high moisture observations. Tractors and machines should be ready when the desired moisture content is approaching.

The operators should practice with the machines to familiarize themselves with the characteristics of their machine. The same operators should be used for all tests with a particular machine.

More work should be done with legume hays to determine the economic feasibility of outside storage of high nutrient hays when fed to both beef and dairy cattle.

Work should also be done on proper methods of feeding large packages of hay. New feeding methods should be developed and compared with free choice and sliding gate feeders equipped with and without roofs. Feeding trials should be done either inside or during a dry season to more accurately determine the amount of waste due to various feeding methods.

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APPENDIX

TABLE 6. Analysis of variance for packaging capacities (metric tons per hour) of the three systems used.

Source of Variation	Degrees of Freedom	Sum of Squares[a]	Mean Square	F Value[b]
		Bermudagrass, Cutting No. 2		
Moisture	1	75.36701	75.367012	5.65665*
Treatment (Machines)	2	1135.56581	567.782905	42.61477**
Moisture X Treatment	2	17.24656	8.623224	0.64721
Residual	18	239.82515	13.323619	
Corrected Total	23	1468.00442	63.826279	
		Lespedeza		
Moisture	1	374.46752	374.467523	120.09882**
Treatment (Machines)	2	948.42119	474.210595	152.08831**
Moisture X Treatment	2	565.61763	282.808813	90.70214
Residual	18	56.12391	3.117995	
Corrected Total	23	1944.63025	84.549141	

*Significant at $\alpha = 0.05$.

**Significant at $\alpha = 0.01$.

[a]The sum of squares were calculated for SI units of measurement.

[b]The residual was used as the error mean square.

TABLE 7. Analysis of variance for handling capacities (metric tons per hour) of the three systems used.

Source of Variation	Degrees of Freedom	Sum of[a] Squares	Mean Square	F Value[b]
		Bermudagrass, Cutting No. 2		
Moisture	1	17.766190	17.7661901	2.14201
Treatment (Machines)	2	3.998155	1.9990776	0.24102
Moisture X Treatment	2	41.938732	20.9693658	2.52821
Residual	18	149.295002	8.2941668	
Corrected Total	23	212.998079	9.2607860	
		Lespedeza		
Moisture	1	26.803292	26.8032924	7.85985**
Treatment (Machines)	2	90.544595	45.2722976	13.27573**
Moisture X Treatment	2	9.566873	4.7834366	1.40270
Residual	18	61.382788	3.4101549	
Corrected Total	23	188.297549	8.1868499	

**Significant at $\alpha = 0.01$.

[a]The sum of squares were calculated for SI units of measurement.

[b]The residual was used as the error mean square.

TABLE 8. Analysis of variance for density of hay packages.

Source of Variation	Degrees of Freedom	Sum of[a] Squares	Mean Square	F Value[b]
		Bermudagrass, Cutting No. 2		
Moisture	1	2692.32	2692.32	0.10449
Treatments (Machines)	2	2471852.63	1235926.31	47.96566**
Moisture X Treatment	2	1505.27	752.64	0.02921
Residual	18	463804.18	25766.90	
Corrected Total	23	2939854,40	127819.76	
		Lespedeza		
Moisture	1	49734.53	49734.53	3.13783
Treatments (Machines)	2	879895.54	439947.77	27.75698**
Moisture X Treatment	2	13699.99	6849.99	0.43218
Residual	18	285299.76	15849.99	
Corrected Total	23	1228629.82	53419.68	

**Significant at $\alpha = 0.01$.

[a]The sum of squares were calculated for SI units of measurement.

[b]The residual was used as the error mean square.

TABLE 9. Analysis of variance for percentage consumption of hay packages during feeding trials.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value
	Bermudagrass Stored Outside (First Week)			
Treatment (Bale Type)	2	6884.151	3442.076	19.542*
Package/Treatment[a]	3	528.404	176.135	
Days	5	21192.389	4238.478	98.934**
Treatment X Day	10	2326.382	232.638	5.430**
Residual	15	642.621	42.841	
Corrected Total	35	31573.947	902.112	
	Bermudagrass Stored Outside (Second Week)			
Treatment	2	158.830	79.415	0.194
Package/Treatment	3	1230.664	410.021	
Day	3	26168.185	8722.728	206.650**
Treatment X Day	6	76.407	12.730	0.302
Residual	9	379.891	42.210	
Corrected Total	23	28013.376	1217.972	
	Lespedeza Stored Outside (Third Week)			
Treatment	2	3541.840	1825.930	12.266*
Package/Treatment	3	446.583	148.861	
Day	2	9652.111	4826.655	76.369**
Treatment X Day	4	1126.722	281.680	4.457*
Residual	6	379.167	63.194	
Corrected Total	17	15256.444	897.438	

TABLE 9. (Continued).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value
Bermudagrass and Lespedeza Stored Inside (Fourth Week)				
Treatment	2	147.444	73.722	0.281
Package/Treatment	3	785.458	261.819	
Day	2	20522.194	10261.097	57.463**
Treatment X Day	4	298.222	74.556	0.417
Residual	6	1071.417	178.569	
Corrected Total	17	22824.736	1342.631	

*Significant at $\alpha = 0.05$.

**Significant at $\alpha = 0.01$.

[a]Nested design, package within treatment.

VITA

David Ronney Robertson was born in Selmer, Tennessee, on October 7, 1951. He is the eldest son of James Alton and Marie Droke Robertson. He has two brothers: Rickey Lynn, Mark Anthony, and a sister, Julie Ann. He spent his childhood and youth on a farm in Hardin County, Tennessee; and after graduation from Hardin County Central High School, he entered The University of Tennessee at Martin in September, 1969. He majored in Agricultural Science and was active in the Agriculture Club, Alpha Zeta, and the Alpha Gamma Rho Fraternity. After receiving his Bachelor of Science degree in August, 1973, he began work as a Graduate Research Assistant for the Agricultural Engineering Department at The University of Tennessee in September, 1973. He also began his graduate work for a Master of Science degree in Agricultural Mechanization in the fall of 1973. While at the University he was involved in the Agricultural Mechanization Club, U.T. Flying Club, Sailing Club, Skiing Club, and the Graduate Student Council. He was also initiated into Gamma Sigma Delta. He will graduate from The University of Tennessee with a Master of Science degree in December, 1975.