To the Graduate Council:

I am submitting herewith a thesis written by Patricia Moore High entitled "Feed Bunk and Headgate Requirements for Large Hay Packages." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

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FEED BUNK AND HEADGATE REQUIREMENTS FOR LARGE HAY PACKAGES

A Thesis

Presented for the

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Degree

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Patricia Moore High

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ABSTRACT

Roofed and unroofed feed bunks and two metal headgate systems were designed and tested with the objective being to evaluate trampling and refused hay feeding losses and package type preference. Outside stored stacks, high-density rolls, and low-density rolls of Midland bermudagrass hay were fed randomly in each feeder type during a three-week feeding trial. Hay trampling loss and refusal loss for each feed bunk type, headgate design, and package type were determined. Cattle preference among package types was noted by visually observing the accumulative percent of each package consumed daily.

Roofed feed bunks had approximately half as much refused hay losses as the unroofed feed bunks with trampling losses being similar. Two headgate suspension systems were studied in the unroofed feed bunks. The pin-jointed, four-bar, straight-line-motion suspension system and the four-guide, sliding suspension system had similar hay losses. Of the three package types studied, stacks were the most fully consumed and preferred. Low-density rolls were the least preferred as well as the least fully consumed. High-density rolls occupied a middle position.

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INTRODUCTION

Food shortages and increased grain and labor prices have focused attention on low-cost beef production from forage crops. Economical hay production is necessary to grow competetively-priced beef. The recent acceptance of large-package haying machinery by farmers (17) has brought the need for an efficient feeding system for large package hay.

Hay, once the largest acreage crop statewide, was surpassed by soybeans in acres produced during the early 1970's, while cattle remained number one in value of production (30). With the price of beef at an all time high in 1978, the commercial beef operator is currently being forced to modify and develop systems of forming, storing, and feeding large hay packages (3). The overall objective of this study was to design, build and evaluate efficient feed bunks with movable headgates for large packages of hay. These feeding systems were to minimize hay losses and were to require minimum attention. Specific objectives were: (1) To compare roofed and unroofed feed bunks for effect on refused hay and trampled hay losses; (2) To compare a sliding gate suspension system with a straight-line-motion linkage gate suspension system for effective operation and effect on trampling losses; and (3) To compare three large hay package types for cattle preference when fed in the feed bunks with moving gates.

Several large package haymaking machines are currently being manufactured. Of the machines available, a Hawk Bilt low-density roll baler, a John Deere high-density roll baler, and a Hesston stacker were used to package Midland bermudagrass (Cynodon dactylon) hay at Ames Plantation. This hay was stored outside and fed the following winter in a three-week feeding trail to determine the percentage wasted in feeding. The hay was fed both in floored and roofed, and in floored unroofed feed bunks. The unroofed bunks had two different headgate designs: A pin-jointed, four-bar, straight-line-motion suspension system, and a four-guide, sliding suspension system. Trampling loss and refused hay loss were recorded and analyzed for roofed and unroofed bunk comparisons, headgate comparisons, and package type comparisons. The percentage of each bale consumed per day was also noted.

CHAPTER II

REVIEW OF LITERATURE

I. THE DEVELOPMENT OF CURRENT HAY PACKAGING MACHINES

"Make hay while the sun shines" brings to mind hours spent in back-breaking physical labor during the hottest periods of the summer. However, increasing labor cost for hay making and decreasing labor availability have led to machines that mechanically handle hay. Cylindrical rolls of hay and stacks with curved tops which shed water led to outside storage and the removal of another production cost. Studies of early haying methods revealed that hay stems placed in a curved configuration produced a "thatched roof" surface similar to the "thatched roof" used on houses in tropical areas. Large-packaging haying machinery, then, evolved around the development of packages sufficiently large for efficient mechanical handling yet compacted and shaped so as to withstand weathering in outside storage without serious loss of quality.

Martin (8) investigated mechanized hay stacking in 1958. He described a hay cage that molded a stack into a desirable size and shape. This was a stationary unit requiring hay to be transported to the stacker. More recent hay stack wagons move along the windrow picking up the hay and compressing it in a stack-forming chamber. When completed the stack is either taken to the storage area where unloaded, left in the field to be transported to storage area at a later date, or left and fed where formed.

The hay stack has been a basic tool of farmers for thousands of years. With the exception of the short-lived Allis-Chalmers small round baler, round hay packages are a new concept in hay making.

Haverdink and Buchele (11) began work with large round bales in 1966. 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 weather. They produced four large cylindrical bales by a machine which rolled hay around hydraulically driven spindles. The machine was eventually abandoned because of the inability to produce large uniformly shaped rolls with acceptable densities.

Equipment manufacturers, realizing the need for large package hay making machine techniques, continued the development. In 1971, Floyd (7) reported the design of two successful large balers. One was designed and manufactured by the Vermeer Company. It moved along the windrow picking up hay with a toothed cylinder which conveyed it into a rolling chamber consisting of two sets of belts. The package produced by this method was of high density, weighed about 675 kg (1500 lbs) and was wrapped with twine. The Vermeer high-density roll had nominal dimensions of 1.8 m (6 ft) length and 1.5 to 2.1 m (5 to 7 ft) diameter.

The other round package baler was designed and manufactured by the Hawk Bilt Company. Rolling the hay along the ground, the baler simply rolled up the windrow until a package weighing from 450 to 680 kg (1000 to 15000 lbs) was formed (16). This low-density package was 2.1 m (7 ft) long and 1 to 2 m (3 to 6 ft) in diameter. Both high- and low-density types of round packages could be unloaded at a storage area or where completed in the field.

II. LARGE PACKAGE HAY SYSTEMS

The method of cutting and windrowing hay can be varied in any large package haying system. Hillman and Logan (12) found harvesting losses to be more dependent on drying conditions and hay moisture content at baling than on the machinery types used. The most common method of preparing hay for packaging is through the use of a conventional mower-conditioner and side delivery rake.

Once hay is windrowed and dried to the desired moisture content packaging can begin. According to Bledsoe et al. (1), packaging and handling capacity for Midland bermudagrass hay increased with hay moisture content for an untied roll bale system. For a stacker system, peak packaging capacity was reached at 23 percent moisture (W.B.) The combined cost for packaging and handling was lowest for both a roll baler and a stacker when hay moisture content was between 20 and 25 percent W.B. Hay quality remained satisfactory for hay when packaged at 30 percent moisture W.B.

Stacking alfalfa hay was studied by Weeks et al. (32) who determined that nutritive value was maintained with initial moisture contents of 40 percent W.B. In vitro digestibility was graded excellent for hay stacked at moisture contents as high as 54 percent W.B. This hay was loosely stacked with a package density range from 50 to 115 kg/m^3 (11.4 to 26.1 lb/ft^3). Digestibility, however, decreased with increasing moisture content for large stacks, with no such trend being apparent in small stacks.

Kilgore (13) found 15 percent moisture W.B. to be a minimum moisture content for packaging Midland bermudagrass with a Vermeer roll baler, a Hawk Bilt roll baler, and a Hesston Stakhand No. 10. He concluded, also, that moisture contents exceeding 27.5 to 30.6 percent W.B. increased packaging and handling costs. Robertson (27) found that moisture content of the hay at baling affected the operating characteristics of three hay packaging systems more than the type of hay used. He used a high-density roll baler with twine, a low-density roll baler without twine, and a stacker producing one ton stacks of Midland bermudagrass hay at 24.4 to 18.5 percent moisture W.B. He stated that the high moisture hay slowed operation of the stacker and tended to wrap around and lodge between the large front rollers of the high-density roll baler.

The results obtained by these reserachers indicate that optimum moisture content for hay packaging depends both on the packaging machine and the kind of hay harvested.

Bledsoe (2) observed that a wide choice of hay packaging machines were available and divided them into three major categories. High-density roll balers producing twine wrapped rolls of 360 kg (800 lbs) or 680 kg (1500 lbs) with mean wet weight density of 150 kg/m^3 (9.4 lb/ft^3) were noted to be the most popular machines used by small-farm operators in Tennessee. Low-density roll balers producing 540 kg (1200 lb) packages of 80 kg/m^3 density with and without twine were used in Tennessee but ranked low in popularity. Many larger farms used large compressed stack wagons which produced stacks of 2400 kg (3 tons) or 5400 kg (6 tons). These large stacking units were efficient in packaging and handling large amounts of hay but had purchase prices 1.6 to 2.5 times those of smaller [907 kg (1 ton)] stack wagons. Packaging capacity varied with different hay types and operating conditions. The high-density roll was the only package type which could be moved immediately to storage. Low-density rolls and stacks required a time period to settle and coalesce into stable handling packages.

Bledsoe et al. (1) noted that the more dense packages required lower moisture content at baling for mold free hay. The high-density packages also shed rain water better than low-density ones. High package density decreased air circulation within the hay, giving a slower rate of temperature change and curing than occurred in the lower density packages.

III. HANDLING AND STORAGE

Means to move and handle large hay packages are required for transporting them to storage and feeding areas. As stated previously, producing a hay package that could be easily and effectively handled was a major consideration in both the design and development of the large hay package system (11). Manufacturer's recommendations call for low-density rolls and stacks to be left in the fields a minimum of 24 hours before handling to allow settling and cohesion to occur. Bledsoe et al. (1) allowed stacks and low-density rolls to settle for three weeks before moving.

Various mechanical tools and machines are required to handle large hay packages. Machines currently available include models which can transport one or several packages. Gill (10) stated that farm operators must adopt a transport system that meets their different demands. The amount of hay involved, size of the package, distance to be moved, environmental feeding conditions, and method of feeding were found to be important considerations.

Ten machines capable of handling from one to four bales per load were studied by Renoll et al. (24). Multibale haulers were the quickest way to transport bales to and from storage. A self-loading, two-wheel trailer mover towed by a pick-up truck was recommended over a tractor mounted mover for distances greater than 1.6 km (1.0 mi). Use of a front-end loader on a tractor to transport and load large round bales allowed more precise bale placement but was found to be hazardous in many situations. The two-bale handling system offered the most economy for small farms (less than 500 tons/year of hay produced). The three- and four-bale moving systems were found advantageous for larger operations. Initial investment costs for movers were tabulated by Brooks and Garrison (3). They found prices ranging from $400 for simple, three-point hitch units to $6000 for the larger trailer-type units. Many operators have designed package movers to best meet their particular needs.

Bledsoe et al. (1) found that higher moisture content bales were heavier and increased unloading and stacking times. Higher moisture content stacks were sufficiently heavy to affect the stability of the tractor on which the three-point hitch stackmover was attached. The overall result was a reduction in the relative handling capacity.

While studying high- and low-density roll bales and stacks, Robertson et al. (28) determined that package condition after storage influenced both handling capacity and losses. They found that portions of some packages, low-density roll bales in particular, were lost in transport.

Rider and Boyer (26) made the following recommendations for large package hay storage:

1. Relocate packages on a well-drained site to prevent accumulations 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 each package to insure drainage.
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 stack yard because of fire hazard. Use fire guards to reduce hazards.

Larsen and Ditterline (15) observed a number of changes which occurred during storage of alfalfa hay. A loss of in vitro digestible dry matter was found to occur during storage and was associated primarily with loss of nitrogen free extract. Loss of protein and crude fiber also occurred. Hesston stacks weighing 3175 to 6350 kg (7000 to 14000 lbs) and 1406 to 2359 kg (3100 to 5200 lbs) increased in density during storage while bales weighing 454 to 608 kg (1000 to 1340 lbs) and

2903 to 5262 kg (6400 to 11600 lbs) decreased in density. Volume shrinkage was negatively correlated to initial density without any consistent relation to initial moisture. Dry matter shrinkage, which Renoll (25) called "unaccountable dry matter loss," was positively correlated with all proximate analysis shrinkage and with the in vitro digestible dry matter shrinkage. This work indicated a need for packaging at a higher moisture content but lower density to reduce storage losses. Package dimensions, particular stack width, were considered to affect the rate of air movement though the package and therefore hay quality. Storage of hay packages on a layer of crushed rocks was found by Parsons et al. (22) to increase air flow and substantially decrease weathering losses.

A study concerning storage characteristics of large round bales conducted by Iowa State University, Hawk Bilt Company, and Chevron Chemical Company-Ortho Division (17) used preservatives to maintain hay quality. Methylene-bio-propionate (MPB), a preservative derived from propionic acid, was sprayed on the outside of the bales. This acid treatment was effective in reducing the mold and bacteria counts at day 106 of storage but not at day 30. Mold and bacteria counts increased with increasing moisture contents of the hay at packaging. In addition, clear plastic "caps" were placed on two 20 to 25 percent moisture low-density bales to be stored outside. These "caps" covered the entire length of the bale and extended about one-third of the way down each side of the bale. Bales equipped with "caps" exhibited the best green color and the least amount of mold at the time they were fed. Marley (17) concluded that "For the weather conditions existing during this research project, bales stored outside maintained their quality better than bales of the same moisture content that were stored inside." Differing with this finding, Currence et al. (5) stated: "The sheltering of large hay bales appears to decrease the hay quality losses associated with long-term storage. At the end of the storage period (167 to 203 days), both digestible protein and dry matter digestibility percentage were significantly higher for bales stored inside. Dry matter loss was lower for the sheltered bales." Robertson (28) and Bledsoe et al. (1) also reported that inside storage of large hay packages preserved quality better than outside storage.

IV. FEEDING LARGE HAY PACKAGES

Hay losses occur with any feeding system. Amounts of hay lost depend on the particular feeding system used. The major objective for all feeding systems is to keep losses to a practical minimum level, according to Lacefield et al. (14). He classified the kinds of feeding losses as trampling, leaf shatter, chemical and physical deterioration, fecal contamination, overconsumption, and refusal. They found the extent of these losses depended on feeding method, interval between feedings, amounts fed, weather conditions, and the number of animals fed. Lower losses were associated with the feeding systems requiring high labor inputs and daily feeding.

Lacefield et al. (14) noted that unrestricted animal access to large round bales and stacks resulted in excessive feeding waste. Restrictions such as electric wire, feeding racks, panels, wagons and gates limit access to feed and reduce waste. Hillman and Logan (12) reduced big-package feeding losses from 46 percent to less than 5 percent through the use of either a hay rack or feeding panels on concrete pads. Dry matter losses were reduced one-third by use of panels when feeding sorghum-sudangrass hay in large rolls to nonlactating dairy cows on a private farm in East Tennessee (33). Lechtenbert et al. (16) reduced feeding losses from 39 to 3.7 percent by use of a feeding rack built on a concrete pad. They found that additional hay was required per cow-day for hay fed without racks.

Robertson (28) observed a difference in cattle preference for three kinds of large hay packages. Low-density stacks were the most preferred followed by high-density rolls, then low-density rolls. He concluded that cattle like to eat from hay packages that provide the easiest obtainable food.

Bledsoe (2) stated that climate affects waste and feeding equipment requirements. In areas having dry or frozen ground during feeding periods, panels that cattle can push inward toward the hay package work well. Circular and rectangular fixed-geometry panels that encircle roll bales are satisfactory for dry feeding areas. In muddy feeding areas and during rainy weather, floored and roofed feed bunks are recommended. Robertson et al. (27) reported trampling losses below 5 percent under rainy, wet conditions when floored and roofed feed bunks were used to feed large hay packages. Bledsoe (2) observed that slanted-bar access openings in panels and racks kept cattle from pulling large portions of hay outside the feeder where it could be trampled into the mud.

Gill (1) reported that feeding losses can be kept reasonably low if good management practices are followed and if unusually wet weather does not occur. His observation was based on studies of hay feeding losses and package-carrying capacities with gestating ewes and beef cattle. He found losses were substantially greater in wet periods using unroofed feeding racks. Wet hay lost palatability and was trampled into the mud. Renoll (25) also observed that rainfall influenced hay losses in packages both in unroofed racks and on sod. Longer daily eating periods, package consumption time and rainfall were found to increase feeding wastes. Renoll et al. (24) pointed out that in wet weather, mud becomes a problem around hay feeding panels. They tried unrolling hay packages on sod daily. This practice was found to require labor needs as great as 2.01 man hours per ton of hay fed and increased waste in wet weather. As hay was unrolled, animals tended to gather and walk on it resulting in contaminated hay.

Brooks and Garrison (3) found that large cattle feed lots and dairies in the Central Plains states processed large package hay for use in their systems. The hay in large round bales or rectangular stacks was cubed or pelleted before feeding. For example, H. J. Kugler and Son of Lexington, Nebraska, packaged hay in large bales and then stored it outside. When needed, it was dried and ground in a special processor and conveyed pneumatically to a storage hopper for mixing. A converted hammermill called a tub grinder or tub mill was the most common processing unit for long hay from any of the large hay packages. Custom operators were often contracted to cut, package, and deliver the packages, usually stacks, to the processing site.

V. MIDLAND BERMUDAGRASS HAY

Quality of hay fed influenced digestibility, weight gains, and hay consumption for beef cattle (21). These factors can, in turn, influence feeding waste. Midland bermudagrass (Cynodon dactylon (L.) Pers. var. Midland), a perennial, warm.season grass, is a hybrid produced by a cross between Indiana and Costal bermudagrass and has proven more winter hardy than Costal. Fribourg et al. (8) found dry matter yields for Midland bermudagrass to exceed 400 kg/ha with proper fertilization and concluded that it is well adapted to Tennessee and produces well in the state. This grass is raised primarily in the southern part of Tennessee at elevations up to 1500 feet (9).

Decher et al. (6) described Midland bermudagrass as a tall, leafy grass producing a high quality, more open sod than common bermudagrass and suited to areas where Costal does not adapt well. Forage quality can be insured by one extra harvest per season. Overton and Fribourg (21) recommended using Midland bermudagrass to overseed established pastures, particular fescue. This practice allows forage growth during the hot midsummer season when fescue is usually dormant. Burns (4) recommended that Midland bermudagrass be cut in the spring when 15 to 18 inches tall with subsequent cuttings three to four weeks apart. Hay quality is lowered by excessive maturity which tends to roughen hay.

CHAPTER III

PROCEDURE

I. PREPARATION OF THE HAY PACKAGES

Two adjoining fields of Midland bermudagrass (Cynodon dactylon) were mowed, conditioned, raked and packaged at Ames Plantation during September 1977. A John Deere Model 1209 mower-conditioner was used to cut a 2.47 m (9.0 ft) swath. Raking was done the following day with a John Deere Model 640 side delivery rake when the hay was within 10 percent of the desired baling moisture content of 20 percent (W.B.). Three different packaging machines were used to package the hay. A Hesston No. 10 Stakhand, produced stacks of hay weighing approximately 1 metric ton (2200 lbs) was one machine used. The stack dimensions were 2.14 m (7 ft) wide, 2.44 m (8 ft) long, and up to 2.44 m (8 ft) high. The second machine used was a Hawk Bilt Model 480 low-density roll baler which produced 159 to 409 kg (350 to 900 lb) rolls not wrapped with twine. These bales were up to 1.83 m (6 ft) in diameter and 2.14 m (7 ft) long. The third machine produced high-density roll packages wrapped with twine; it was a John Deere Model 500 baler. The John Deere bales produced weighed from 324 to 596 kg (714 to 1313 lbs) and measured 1.5 m (5 ft) along and up to 1.83 m (6 ft) in diameter.

Packages were weighed as they were removed from the field. Either a Hesston No. 10 Stackmover or a front-end loader was used to handle the packages. Torque-O-Meter portable highway scales were used to weigh tractor, mover, and package as described by Robertson (28). Tare weights were recorded before and after weighing each package. Three core samples were taken from each package using a Pennsylvania coring tool driven by an electrically powered drill. These samples were used to determine the percentage of moisture in each package.

Storage was outside in an area convenient to the feeding area. The storage area was a well-drained area covered with bermudagrass sod. Packages were spaced a minimum of one foot apart and arranged to be accessible for feeding.

II. FEEDING SYSTEMS

The three feeding systems were: (1) four floored and roofed bunks with sliding wooden gates; (2) two floored, unroofed bunks with sliding metal gates; and (3) two floored, unroofed bunks with straight-line-motion motion linkage suspended gates. Eight feeders were spaced approximately 6 m (20 ft) apart in an "L" formation along a fence-line corner.

The eight feed bunks were made of unfinished oak and were identical with the exception of being either roofed or unroofed. The floor was elevated 20.3 cm (8 in) above ground level to prevent water and mud from entering the feeder. The two main floor supports served as skids for moving the bunks from location to location. The feed bunk floor inside dimensions were 2.74 m (9 ft) by 3.05 m (10 ft). The geometry of the two feed bunk designs is shown in Figure 1. An enlargement of the metal angles added for structural rigidity is shown in Figure 2.

Side support columns on the four roofed feed bunks were extended upward 3.05 m (10ft) from the floor to support the roof. These feeders

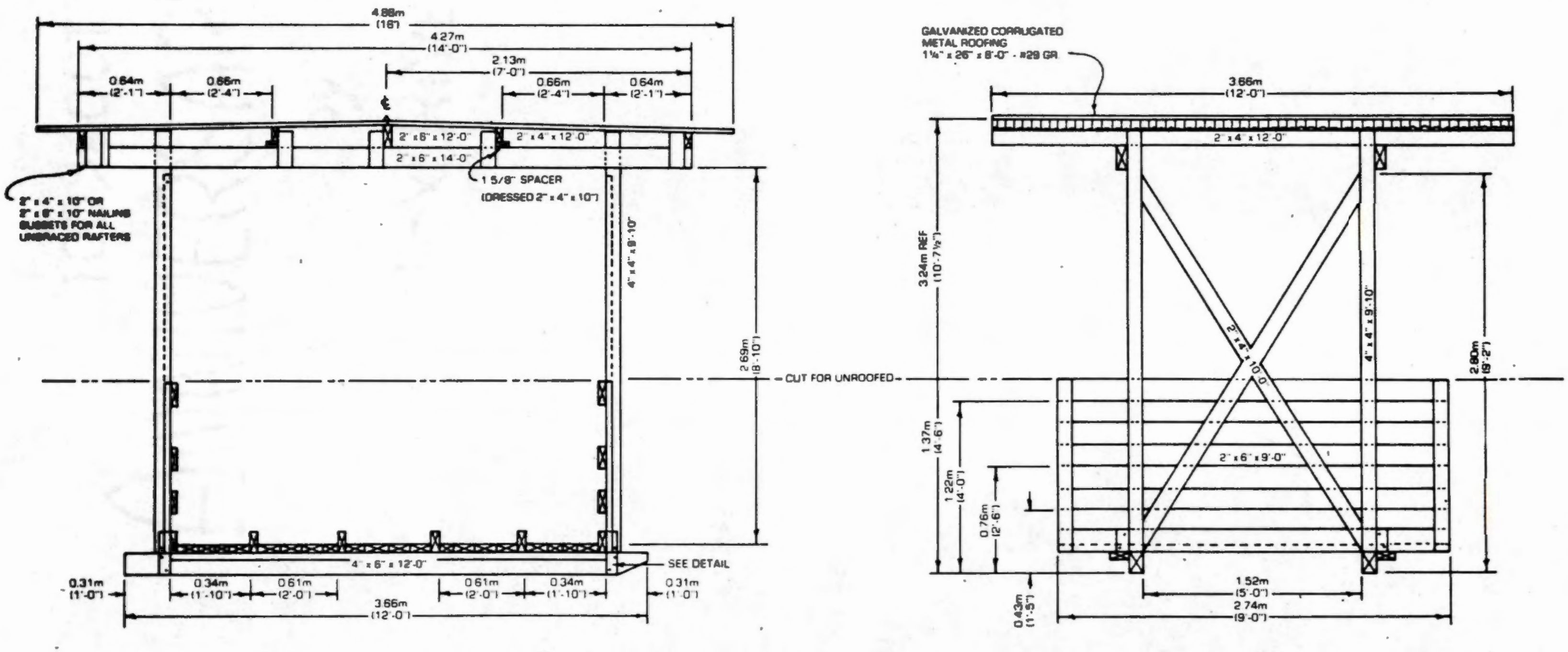


Figure 1. Dimensional drawing of roofed and unroofed feed bunks. Note line indicating superstructure added to the roofed feed bunk.

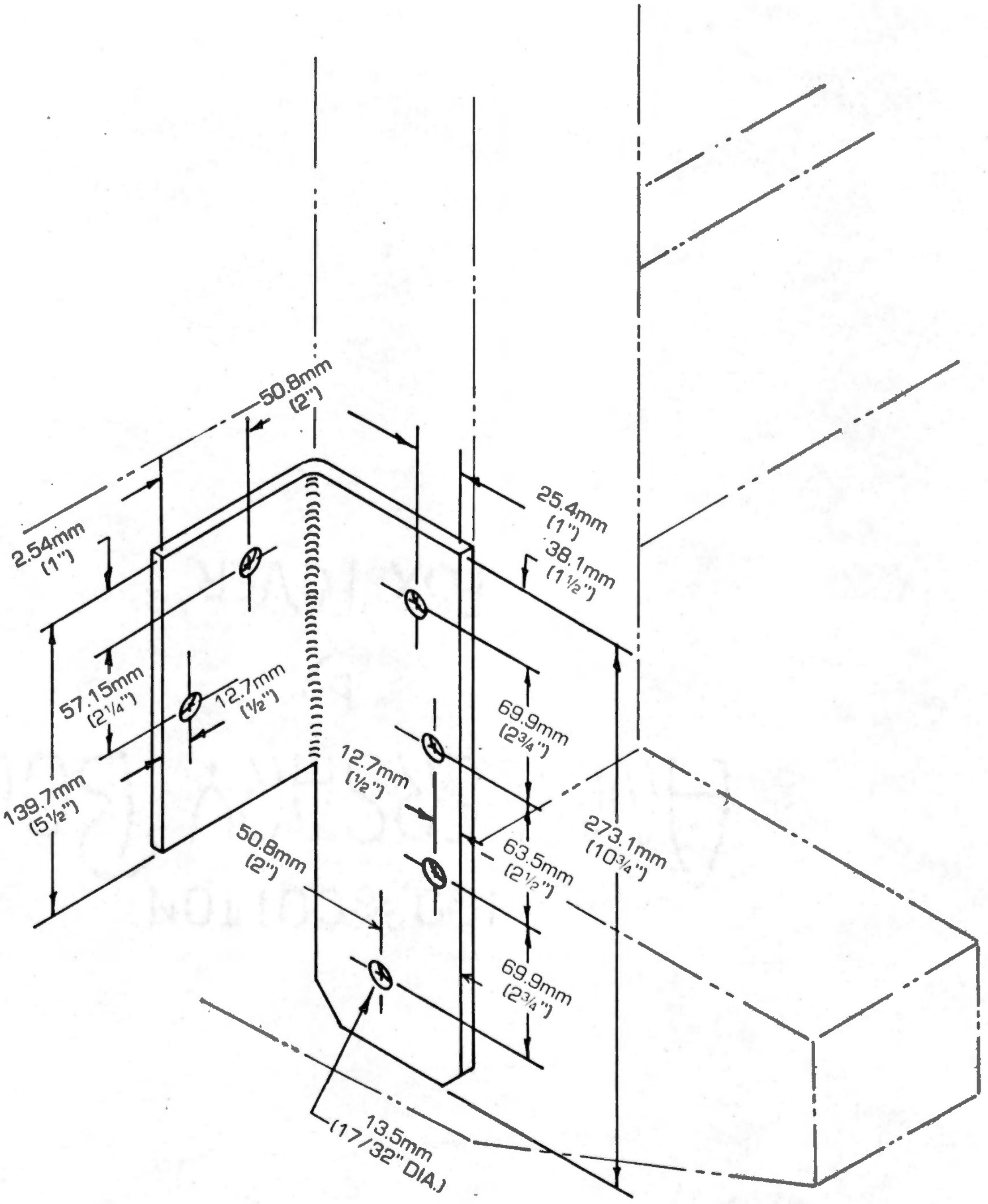


Figure 2. Four metal reinforcing angles were used for each feed bunk to add torsional rigidity for transport and to prevent warping.

were used by Robertson in 1974 and were in good condition. The headgates were made of wood and were fitted with two cut-out pipe brackets on the bottom which allowed sliding of the gate along two pipe lengths mounted on the feed bunk floor. These headgates required two people to remove and replace them when a new hay package was to be placed in the bunk. Slanted boards were positioned about 40 cm (15 in) apart on the gates to provide cattle access to the hay. The slanted-board openings forced cattle to turn their heads before backing away from the bunk and thus reduced trampling loss, according to Robertson (28). This feed bunk and headgate are shown in Figure 3.

Two headgate designs were installed on the unroofed feed bunks. A pin-jointed, four-bar, straight-line-motion suspension system and a four-guide, sliding suspension system were built in the Agricultural Engineering Shop at The University of Tennessee, Knoxville. The headgates were constructed of 31.8 mm (1 1/4 in) square metal tubing. Cattle access openings consisted of slanted metal bars spaced 45.7 cm (18 in) apart and inclined at a 30° angle.

The pin-jointed suspension system, a modified Robert's straight-line linkage (31), was basically an isosceles triangle fastened by pin joints to two identical lengths of tubing which were in turn attached to the bunk sides. A schematic diagram of the pin-jointed suspension system giving the range of motion is whown in Figure 4. An exploded view drawing of the mechanism is shown in Figure 5. Figure 6 is a photograph showing the assembled headgate suspension system.

The sliding gate system was basically the same headgate as used for the pin jointed system with four metal slider brackets, one on each

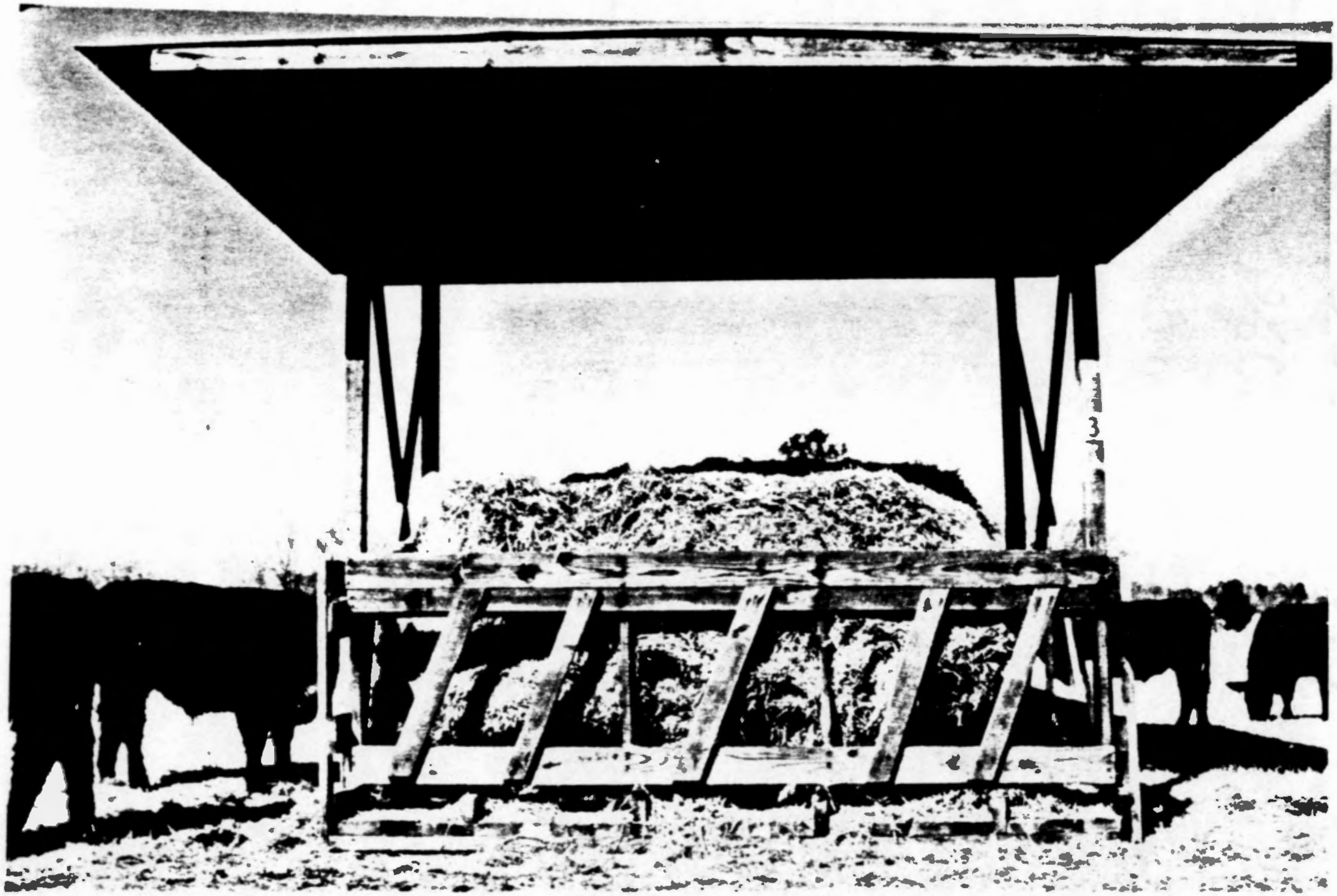


Figure 3. Low-density stack inside wooden headgate-roofed feed bunk system.

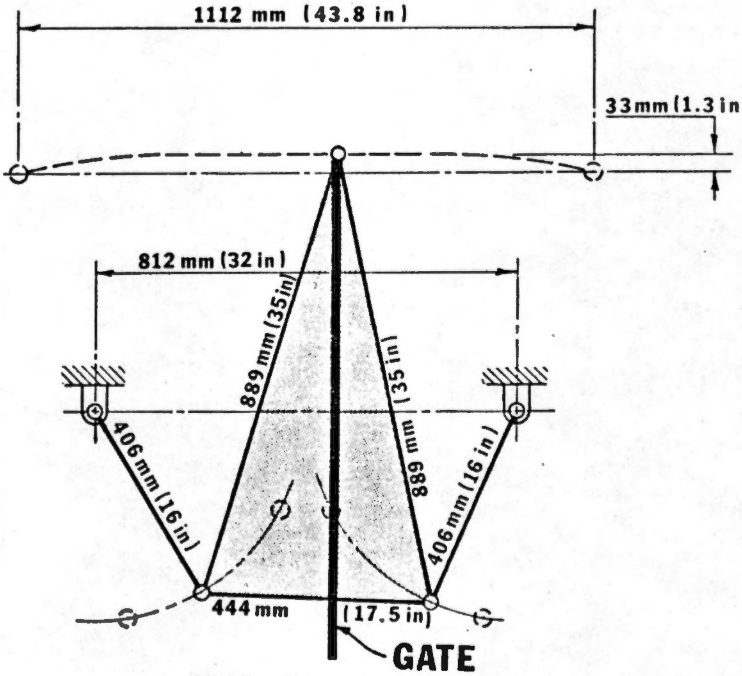
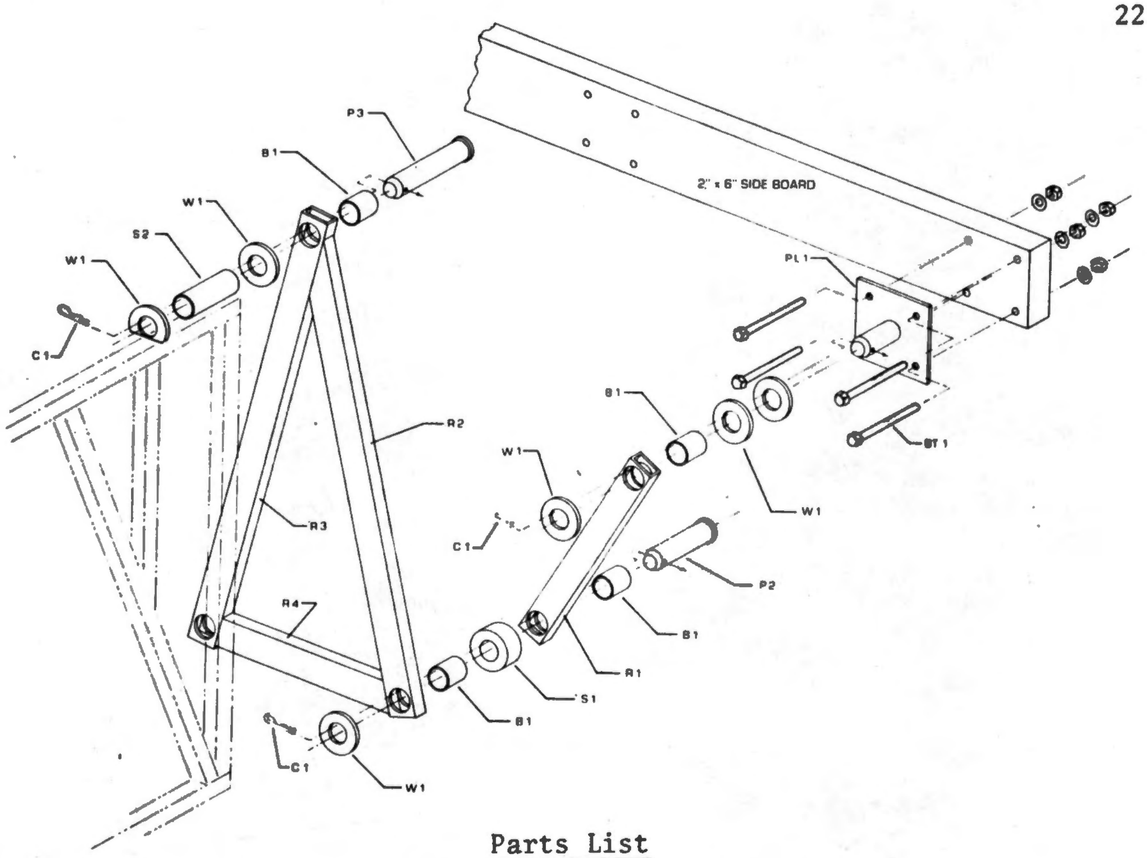


Figure 4. Schematic diagram of the pin-jointed, straight-line suspension system showing the range of possible motion.



Parts List

Part No.	Quantity Per Gate	Description
P2	2	1.49" O. D. × 4.64" Long Rod
P3	2	1.49" O. D. × 6.31" Long Rod
B1	8	1 5/8" O. D. × .065" Thick × 1.25" Long Round Tub. Stl.
W1	12	3 1/4" O. D. × 0.18" Thick Plain Washer
R1	4	1" × 2" Rec. Tub. Stl. × 18.5" Long
R2	2	1" × 2" Rec. Tub. Stl. × 34.95" Long
R3	2	1" × 2" Rec. Tub. Stl. × 35.94" Long
R4	2	1" × 2" Rec. Tub. Stl. × 15.95" Long
S1	2	1.527" I. D. × 1.26" Thick Spacer
S2	2	1 5/8" O. D. × .065" Thick × 4" Long Round Tub. Stl.
PL1	4	1.49" O. D. × 2.74" O. D. Rod Wielded to a 6" × 6" × 1/4" Stl. Plate
BT1	6	1/2" Dia. × 5" Long Bolt
BT2	10	1/2" Dia. × 3" Long Bolt
C1	6	1/8" Clip Pin × 2" Long For Pins P1, P2, P3

Figure 5. Exploded view and parts list for the pin-jointed suspension system.

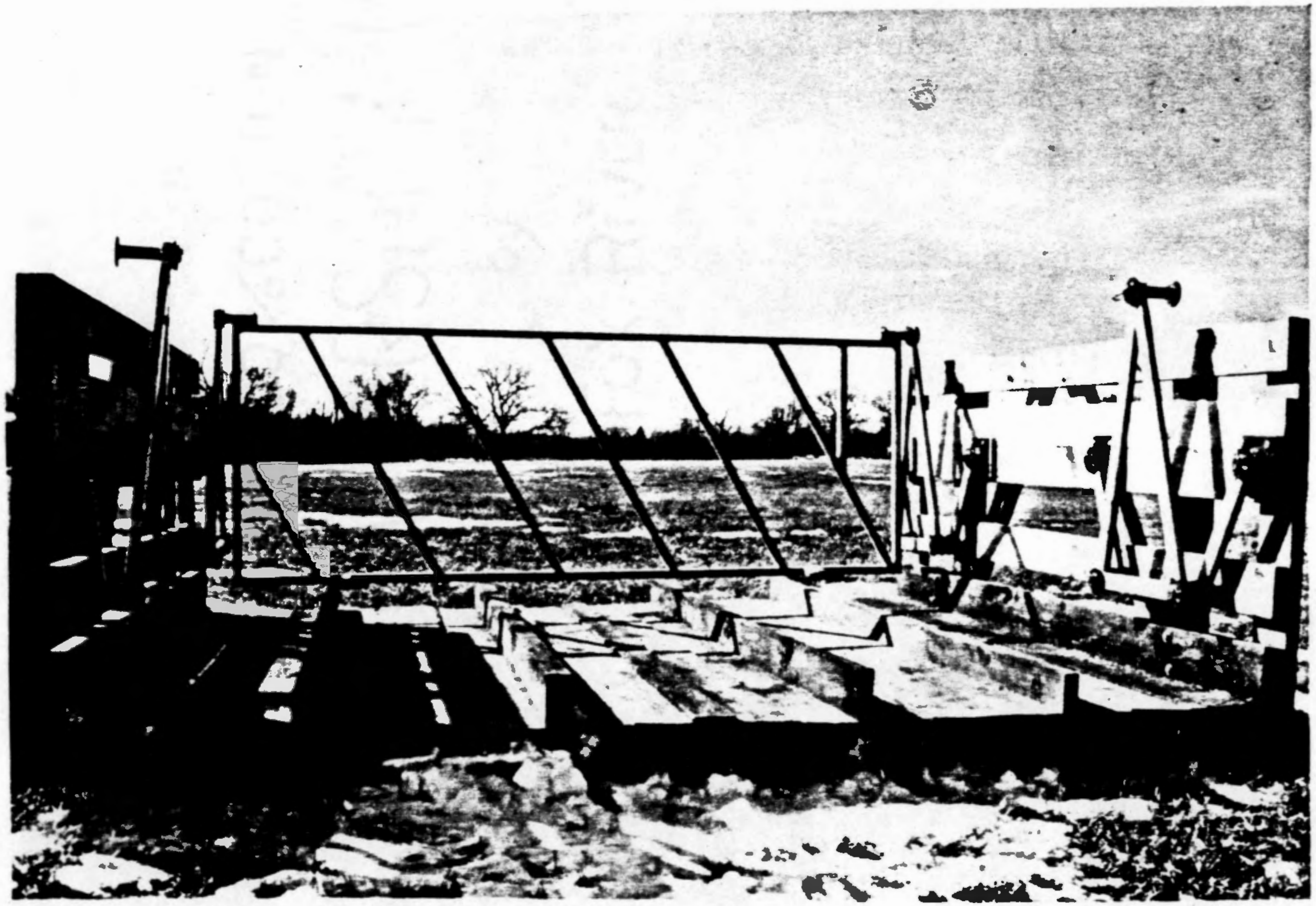


Figure 6. Unroofed feed bunk showing pin-jointed system with and without headgate attached.

corner, sliding on support pipes. The structure and dimensions of the headgate are shown in Figure 7. The support pipes were mounted, two on each side, inside the feed bunk by eight small pipe sections slightly larger than the diameter of the support pipe (Figure 8). The support pipes were 7.3 cm (2-7/8 in) O. D. standard pipe.

III. FEEDING TRIAL

Twenty-four large hay packages of three different types were fed to 125 Black Angus steers weighing approximately 272 kg (600 lbs) each. Ten high-density rolls, nine low-density rolls, and five stacks were fed over a twenty-one day period. The feeding area was Field 16 of Ames Plantation which was a 3.21 hectare (3.0 acre) grass lot with water available from a small pond. The feeding trial began February 6, and ended February 26, 1978.

Each hay package was core-sampled and weighed immediately before beginning the feeding trial. An attempt was made to feed one of each package type in each of the three feeder designs during each week of the feeding trial. This was impossible, however, due to a shortage of usable stacks. Four stacks were destroyed in transport. Four stacks, two high-density rolls, and two low-density rolls were placed into eight feed bunks comprising the three feeding systems. These initial hay packages were consumed in eight days. On February 15, 1978, all feeders were refilled using six high-density rolls, one low-density roll, and one stack. The third set of hay packages were placed in the feed bunks on February 21, 1978, using two high-density rolls, and six low-density

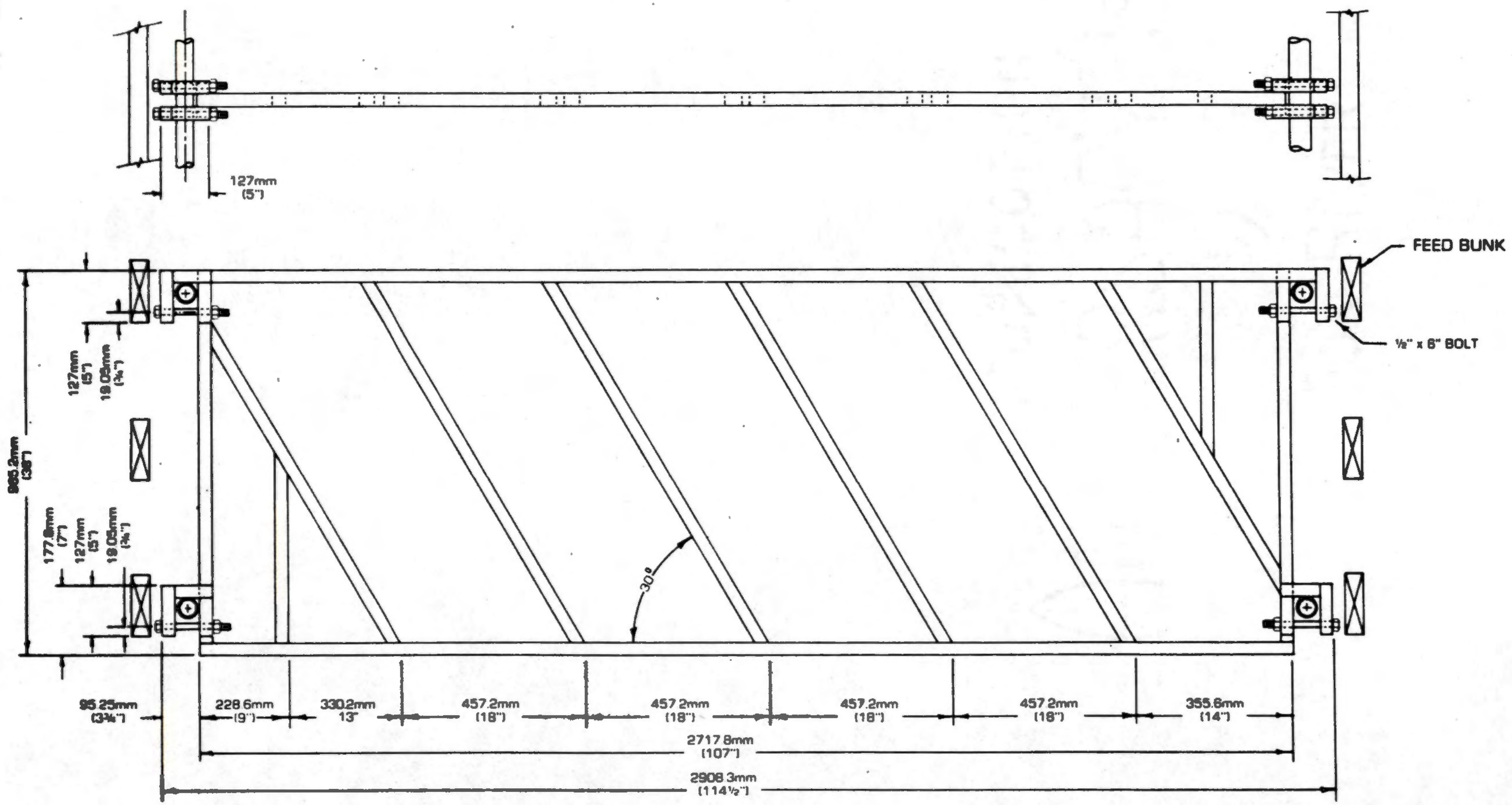


Figure 7. Dimensional drawing showing front and top views of the headgate used in the sliding suspension system.

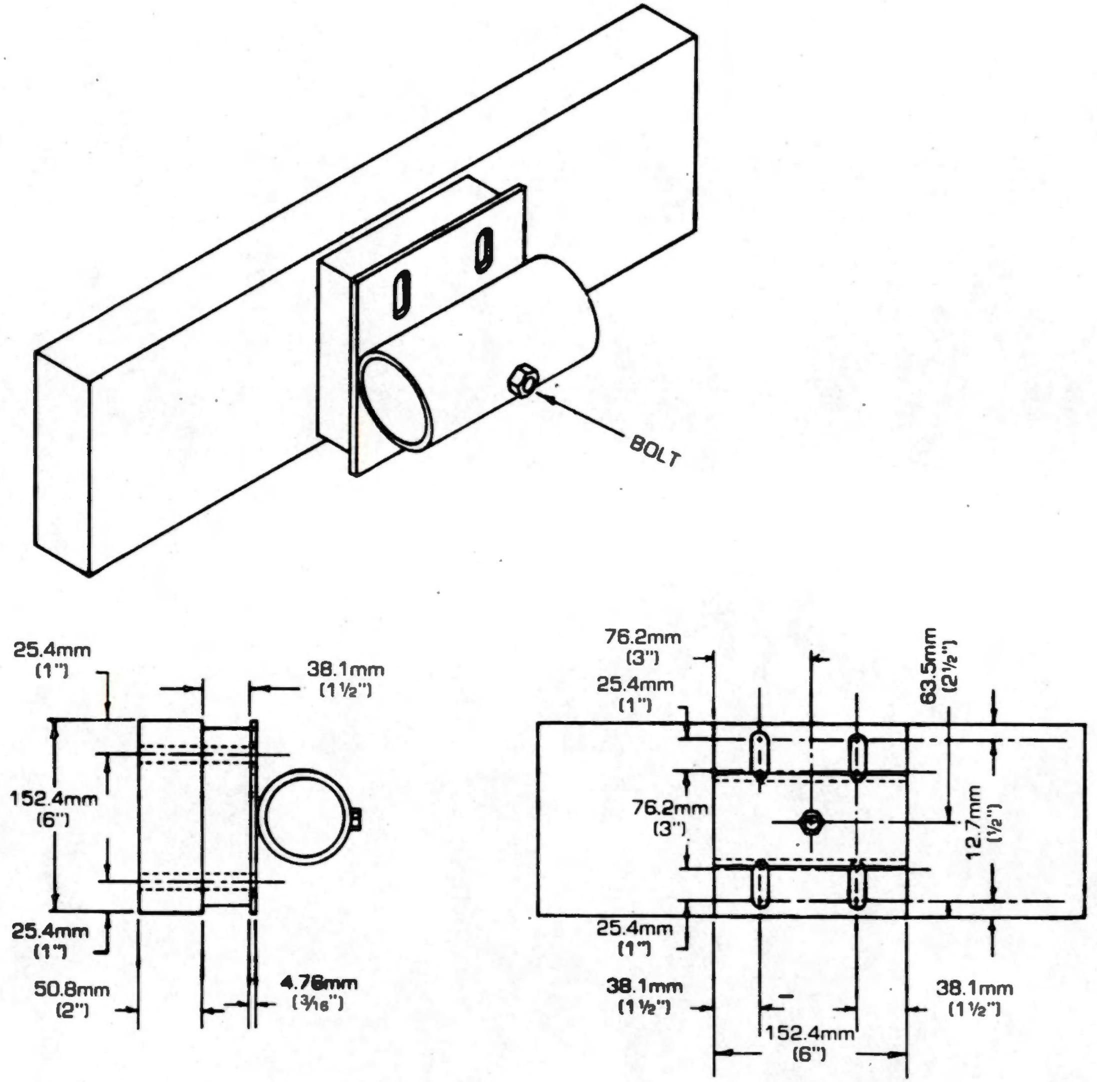


Figure 8. Dimensional drawing of the support pipe mounting brackets.

rolls. New hay packages were put in the bunks (refilling) when the cattle stopped eating the remains of old packages and began walking the fence-line, bellowing for food. At this time the remaining or refused hay was removed and weighed. To keep all gates working freely, grease was applied to the pipe lengths of the wooden headgate system and the guides of the sliding gate system each time the hay bunks were refilled.

With one headgate removed from each feed bunk, a package was placed inside. High-density packages were placed on end (with long axis perpendicular to the feed bunk floor). Stacks and low-density rolls were positioned so the long axis of each package was parallel to the floor. A tractor equipped with either a front-end loader or a three-point-hitch stackmover was used for filling the feeders. Figure 9 shows the three-point-hitch stackmover being used to position a stack in an unroofed feeder. A correctly positioned stack in a sliding suspension headgate system is shown in Figure 10. The twine was cut on the high-density roll packages but not removed before headgates were replaced.

Cattle had access to the hay by inserting their heads through the diagonal headgate slots. While eating, cattle naturally pushed the gates inward with their withers, squeezing the remaining hay into a smaller space between the headgates. This movement of the headgates was designed to keep hay always accessible to cattle and thus to reduce refusal waste.

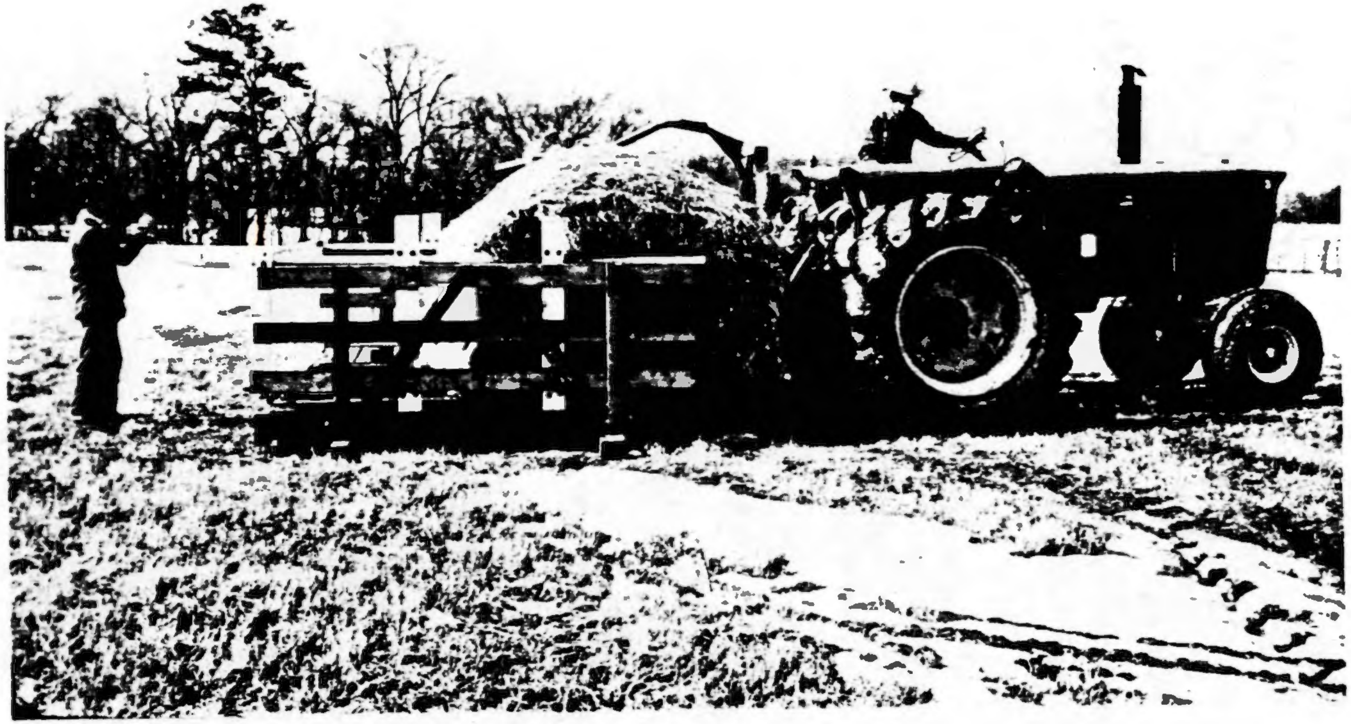


Figure 9. Placement of a stack in an unroofed feed bunk using a three-point-hitch type stack remover.

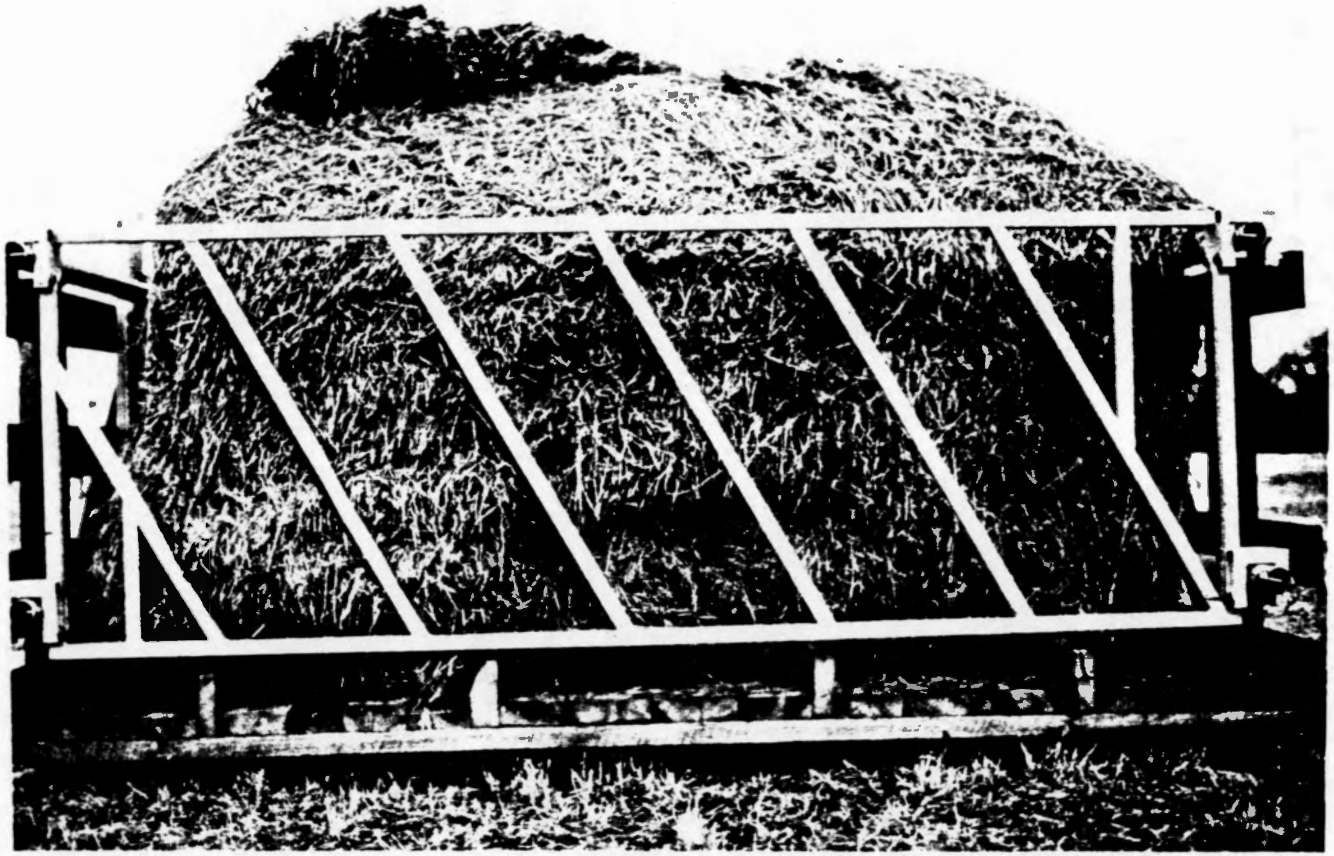


Figure 10. Hay stack inside four-guide sliding suspension headgate feeder.

IV. HAY WASTE

Data were obtained for two types of hay waste: the trampling loss per package and the refused hay per package. The sum of these two losses constituted the total loss per package. Trampling loss refers to the hay which was pulled from the feeder and trampled underfoot on the frozen ground, while refused hay designates hay left within the feeder and not consumed.

Four trampling loss samples were taken daily from around each feeder using four sampling frames, each including an area of 0.37 m^2 (4 ft^2). The area around each feeder was raked daily to remove the remaining trampling loss. These hay samples were dried for 48 hours at 57°C (135° F) and then weighed. From these samples an estimate of the trampling loss per package and per feeder was made. Figure 11 illustrates the trampling loss around a roofed feed bunk. Before refilling each feeder the refused hay was removed, dried, and weighed. These samples were also dried at 57°C (135° F) in a drying oven at Ames Plantation. Much of the refused hay was frozen, requiring the use of axes to obtain hay sections small enough to dry. These large frozen chunks of refused hay are shown in Figure 12. The percentage of each package consumed was recorded daily. This was a visual observation and subjective. It was meant to estimate the rate at which a package was consumed. Using the initial package weight and the actual refused hay weight at the end of the feeding period, a correction ratio was formed and used to correct the visual observations for a more accurate estimate. The corrected

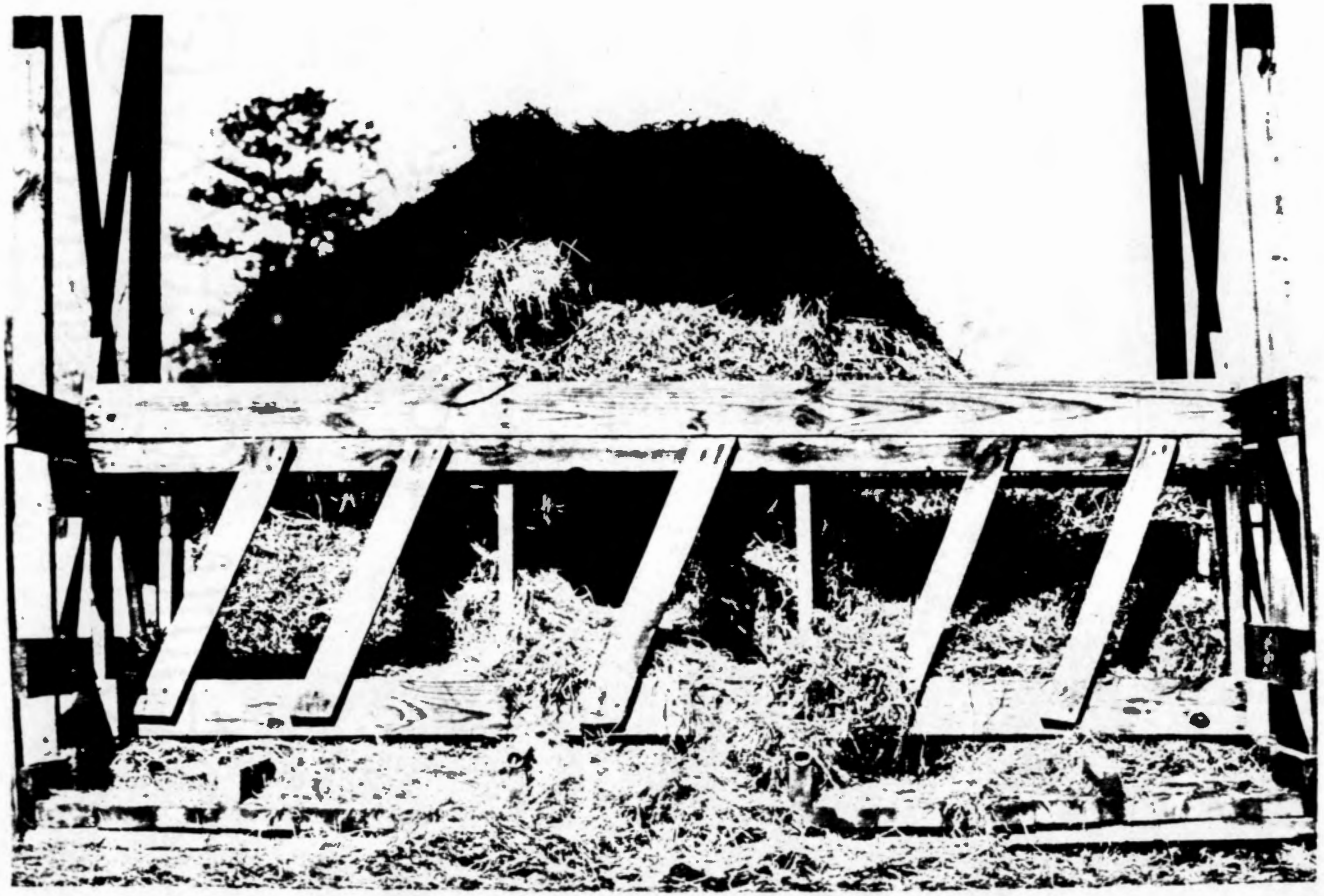


Figure 11. Low-density hay package inside wooden roofed feeder. Note hay around lower position of the headgate and on the ground.

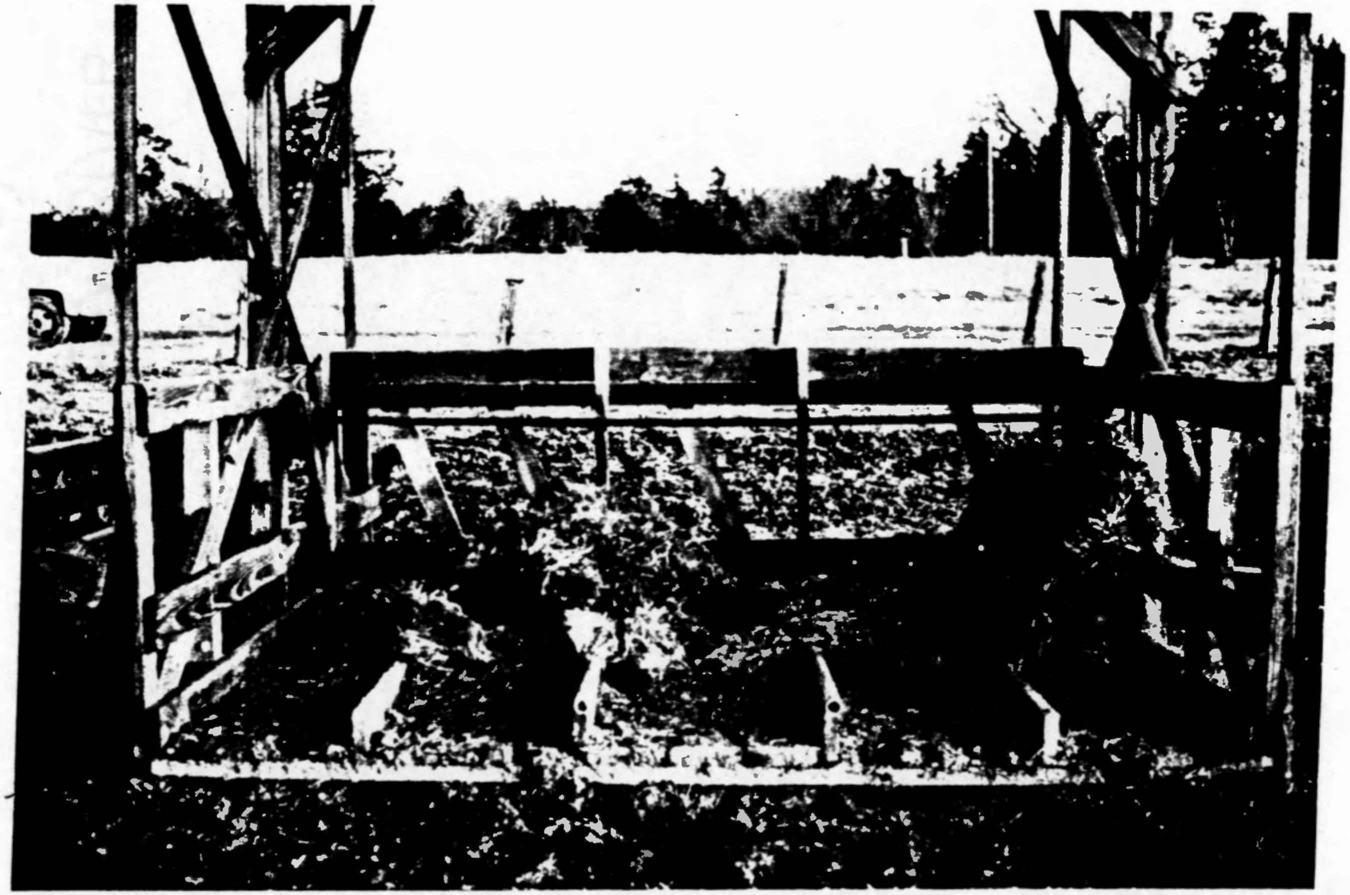


Figure 12. Frozen masses of refused hay in an unroofed feeder. Note the two slider pipes attached on the feed bunk floor.

daily estimate of hay consumption figures gave a realistic measure of cattle preference for hay package type.

A number of procedural problems occurred during the feeding trial. A fire in the dryer destroyed a large portion of the refused hay from one linkage system type feeder and one sliding system type feeder during the third week. These data were thus eliminated from the analysis. The destruction of four stacks required that an unweighed high-density roll bale be fed in one roofed feed bunk during the second week of the feeding trial. This package also was not included in the analysis.

V. STATISTICAL ANALYSIS

The Statistical Analysis System (SAS) computer program package (1979 version) developed by the Statistics Department at North Carolina State University was used for statistical calculations. The SAS program GLM procedure was used to compute analysis of variance tables and least square mean tables. Contrast statements provided for package type comparisons, headgate comparisons, and roofed and unroofed feed bunk comparisons. It should be noted that the roofed and unroofed feed bunk comparison was confounded with the headgate comparison. Response variables were trampling loss, refused hay loss, and cumulative hay consumption measured in kilograms and as a percentage of the original package weight.

Two separate analytical models were developed. Refused hay and trampling loss were used as the response variable being expressed as a weight in kilograms and as a percentage of the original package weight. Sources of variations were the original package weight (omitted in the second model which had loss expressed as a percentage), week, feeder type, package kind, and package kind by feeder type interaction. Appropriate feeder type and package type contrasts were computed. Trampling loss, refused hay, and rate of consumption data were averaged and graphed for each feeding system and package kind.

CHAPTER IV

RESULTS AND DISCUSSION

I. ROOFED AND UNROOFED FEEDER INFLUENCES ON LOSS

Collected data (summarized in Table 1) when analyzed statistically showed that the roofed and unroofed feed bunks had significantly different refused hay losses both by weight and as a percentage of the original package weight (Table 2). Significance was measured at the 5 percent level. The refused hay loss for the roofed bunks was 10.9 percent and was 19.1 percent for the unroofed bunks. The trampling loss for the roofed bunks was 14.0 percent and was 9.7 percent for the unroofed bunks. The unroofed feed bunks had a significantly higher refused loss and a lower, yet statistically nonsignificant, trampling loss as compared to the roofed feed bunks (Table 3). The combined or total hay wasted for the roofed and unroofed feeders was 24.9 percent and 28.8 percent, respectively. Losses for each package by weight (kilograms) are given in Table 1. The large refusal loss can be attributed to rainfall and weather condition effects on the hay and the lower quality normally associated with the September cutting of bermudagrass hay.

The wooden headgates of the roofed bunks tended to lodge or jam frequently, preventing proper sliding of the gates, and were turned over periodically within the feeder. These malfunctions, however, did not seem to affect the trampling loss or hay refusal. Cattle avoided the

Table 1. Summary of feeding data and hay losses.

Bunk Number	Feeder Type	Week	Package Type	Package Weight Kilograms*	Refused Hay Kilograms*	Trampling Loss Kilograms*	Refused Hay Percent	Trampling Loss Percent
1	Roofed	1	High density	595.8	26	15.6	4.6	2.6
2	Roofed	1	Stack	1769.5	30	43.4	1.7	2.5
3	Roofed	1	Stack	2073.5	30	62.3	1.4	3.0
4	Roofed	1	Low density	202.4	26	39.4	12.9	19.5
5	Sliding gate	1	Stack	713.7	126	29.7	17.7	4.2
6	Linkage gate	1	Low density	287.5	126	17.7	43.9	6.2
7	Linkage gate	1	Stack	2023.5	158	35.8	7.8	1.8
8	Sliding gate	1	High density	439.8	120	12.4	27.3	2.8
1	Roofed	2	Low density	409.3	98	16.5	23.9	4.0
2	Roofed	2	ϕ	ϕ	31	8.9	ϕ	ϕ
3	Roofed	2	High density	438.6	56	39.7	12.8	9.0
4	Roofed	2	High density	323.8	33	12.3	10.2	3.8
5	Sliding gate	2	High density	381.6	89	9.1	23.3	2.4
6	Linkage gate	2	High density	471.9	53	73.6	11.2	15.6
7	Linkage gate	2	High density	446.4	48	66.5	10.8	14.9
8	Sliding gate	2	Stack	847.9	37	34.6	4.4	4.1
1	Roofed	3	Low density	371.2	12	108.7	3.2	29.3
2	Roofed	3	Low density	159.0	32	80.6	20.1	50.7
3	Roofed	3	Low density	352.0	50	68.9	14.2	19.6
4	Roofed	3	High density	424.1	111	46.4	26.2	10.9
5	Sliding gate	3	Low density	259.5	ϕ	26.2	ϕ	10.0
6	Linkage gate	3	Low density	331.8	ϕ	31.2	ϕ	9.4
7	Linkage gate	3	Low density	379.4	118	139.9	31.1	36.9
8	Sliding gate	3	High density	409.9	55	30.6	13.4	7.5

*Dry matter basis.

ϕData eliminated from analysis.

Table 2. Analysis of variance for refused hay losses by weight and as a percentage of the original package weight.

Source of Variation	Degrees of Freedom	Mean Square	F Valve[b]
	By Weight		
Dry Package Weight	1	2.10	0.00
Week	2	163.01	0.10
Feed Bunk Kind	2	7069.52	4.81*
Package Type	2	614.44	0.42
Kind × Type	3°	2698.32	1.84
Residual	10°	1468.43	
Corrected Total	20		
Contrast			
Guide vs Linkage	1	577.60	0.41
Roof vs Unroof	1	11660.65	8.30*
	As Percentage of Original Package Weight		
Week	2	14.06	0.21
Feed Bunk Kind	2	250.31	3.61*
Package Type	2	495.60	7.28*
Kind × Type	3°	127.07	1.87
Residual	11°	78.07	
Corrected Total	20		
Contrast			
Guide vs Linkage	1	7.08	0.09
Roof vs Unroof	1	539.28	7.08*
Low vs High Density	1	281.95	3.70*
Stack vs Roll	1	695.55	9.13*

*Significant at $\alpha = 0.05$.

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

°One degree of freedom missing due to missing data. Total of three missing data valves for this analysis. See Table 1.

Table 3. Analysis of variance for trampling loss by weight and as a percentage of the original package weight.

Source of Variation	Degrees of Freedom	Mean Square	F Value[b]
	By Weight		
Dry Package Weight	1	276.92	0.35
Week	2	3235.19	4.10
Feed Bunk Kind	2	162.31	0.21
Package Type	2	179.58	0.23
Kind × Type	4	860.71	1.09
Residual	11°	789.66	
Corrected Total	22		
Contrast			
Guide vs Linkage	1	249.50	0.32
Roof vs Unroof	1	10.08	0.01
Low vs High Density	1	66.01	0.08
Stack vs Roll	1	15.65	0.15
	As Percentage of Original Package Weight		
Week	2	305.28	3.05
Feed Bunk Kind	2	102.16	1.02
Package Type	2	21.33	0.21
Kind × Type	4	111.20	1.11
Residual	12°	100.12	
Corrected Total	22	155.46	
Contrast			
Guide vs Linkage	1	163.50	1.63
Roof vs Unroof	1	43.60	0.44
Low vs High Density	1	1.00	0.01
Stack vs Roll	1	42.65	0.43

*Significant at $\alpha = 0.05$.

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

°Total of one missing data valve for this analysis. See Table 1.

unattached or jammed wodden headgates. Additionally, these headgates were much heavier than the metal gates used with the unroofed bunks making them more difficult to remove and install when refilling the feeders. These factors increased the labor associated with use of the roofed feeders.

II. INFLUENCES OF SLIDING AND LINKAGE HEADGATE SYSTEM ON LOSS

No significant difference in either refusal hay loss or trampling hay loss was indicated between the sliding headgate system and the pin-jointed linkage headgate system (Table 2, page 37). Refusal for the sliding gate system was 17.2 percent and was 19.1 percent for the linkage gate system. The similar losses can be attributed to both systems being unroofed and the similar headgate designs.

The trampling loss varied greatly from week to week and among package types. A number of operating problems occurred with the linkage system design. While no tendency to jam was noted, the cattle could remove the clips from the linkage pins allowing the pins to fall out. This hampered headgate movement and allowed the cattle to reach over the headgate and pull excessive amounts of hay out of the feeder. Another design problem also was noted. Headgates could swing outward as well as be pulled outward. This was more of a problem with hay stacks. Cattle would eat the base of the stacks first creating an unstable mushroom shape. The upper portion of "mushroom cap" would then fall against one headgate pushing it outward as shown in Figure 13. This condition allowed hay to extend over the feed bunk edge and onto the ground,

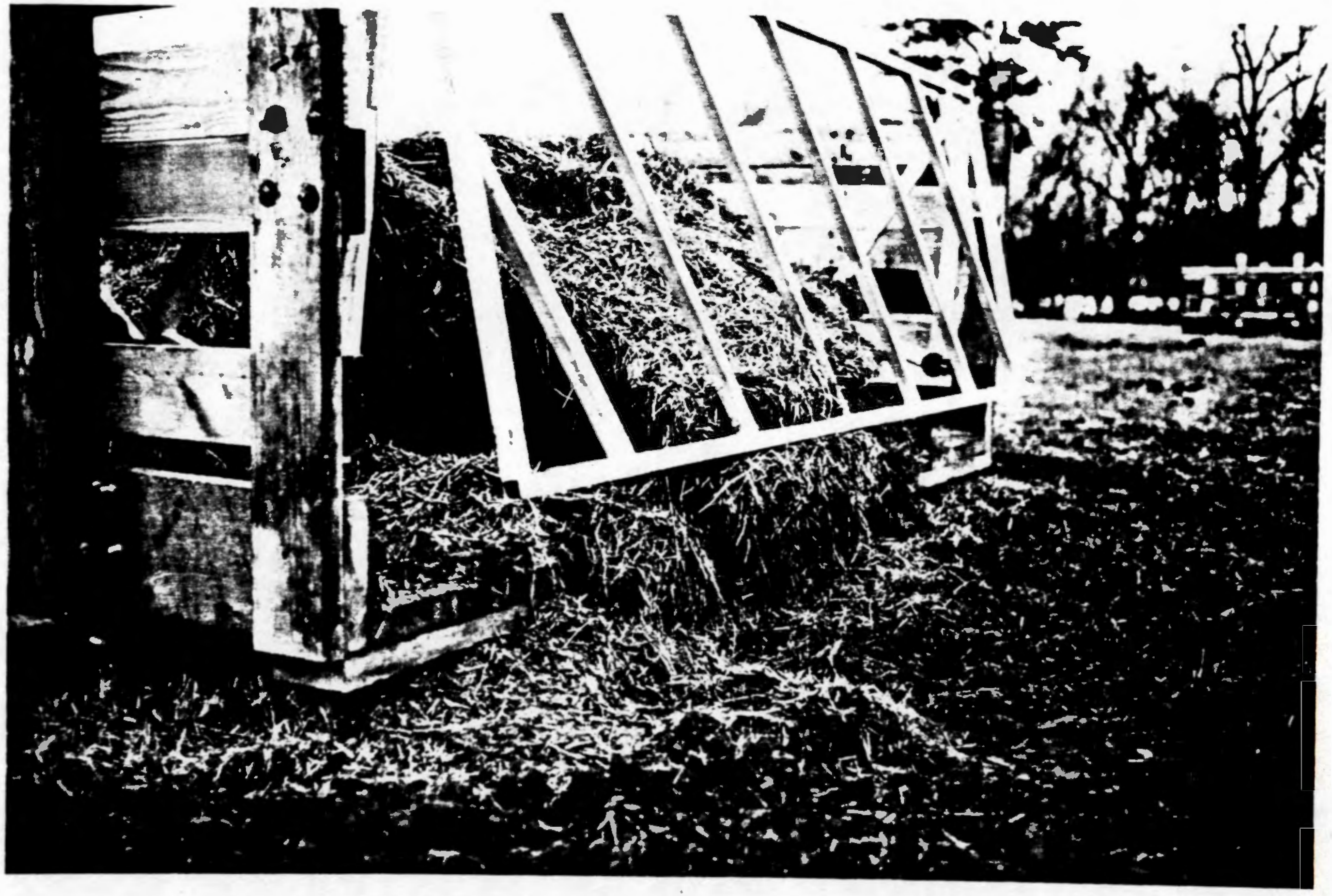


Figure 13. Collapse of frozen "mushroom cap" portion of a hay stack pushed linkage system headgate outward.

greatly increasing the trampling loss. A number of unsuccessful attempts were made during the feeding trial to establish some type of stop mechanism to correct this problem. An average trampling loss of 14.2 percent occured with the linkage system.

The four-guide, sliding headgate system had a trampling loss of 4.2 percent. This is much less than the 14.2 percent observed for the linkage headgate system. The sliding headgates were more difficult to install due to the importance of guide pipe alignment influence on jamming. This headgate system worked well throughout the testing period with the exception of occasional jamming. Warping of the feed bunk structure to change the guide alignment could create severe jamming problems. Figure 14 illustrates the normal trampling loss pattern for this design. The headgates in the sliding system also were more difficult to remove for refilling the feeder than the gate of the linkage system.

Combining the trampling loss and the refused hay loss gives a total loss figure. The linkage gate system had a total hay loss of 33.2 percent while the sliding gate system showed a 22.4 percent total loss (Figure 15).

III. WEATHER INFLUENCES

During the 21-day testing period, temperatures remained much lower than average with all precipitation occurring as snow (Figure 16). Snow on occasion melted and soaked into packages merely to be refrozen in the outer shell. The ambient temperature went below freezing every day (Figure 17). Round hay packages were frozen to the ground and required

Figure 14. Normal consumption pattern and trampling loss for a low-density package in a sliding headgate unroofed system.

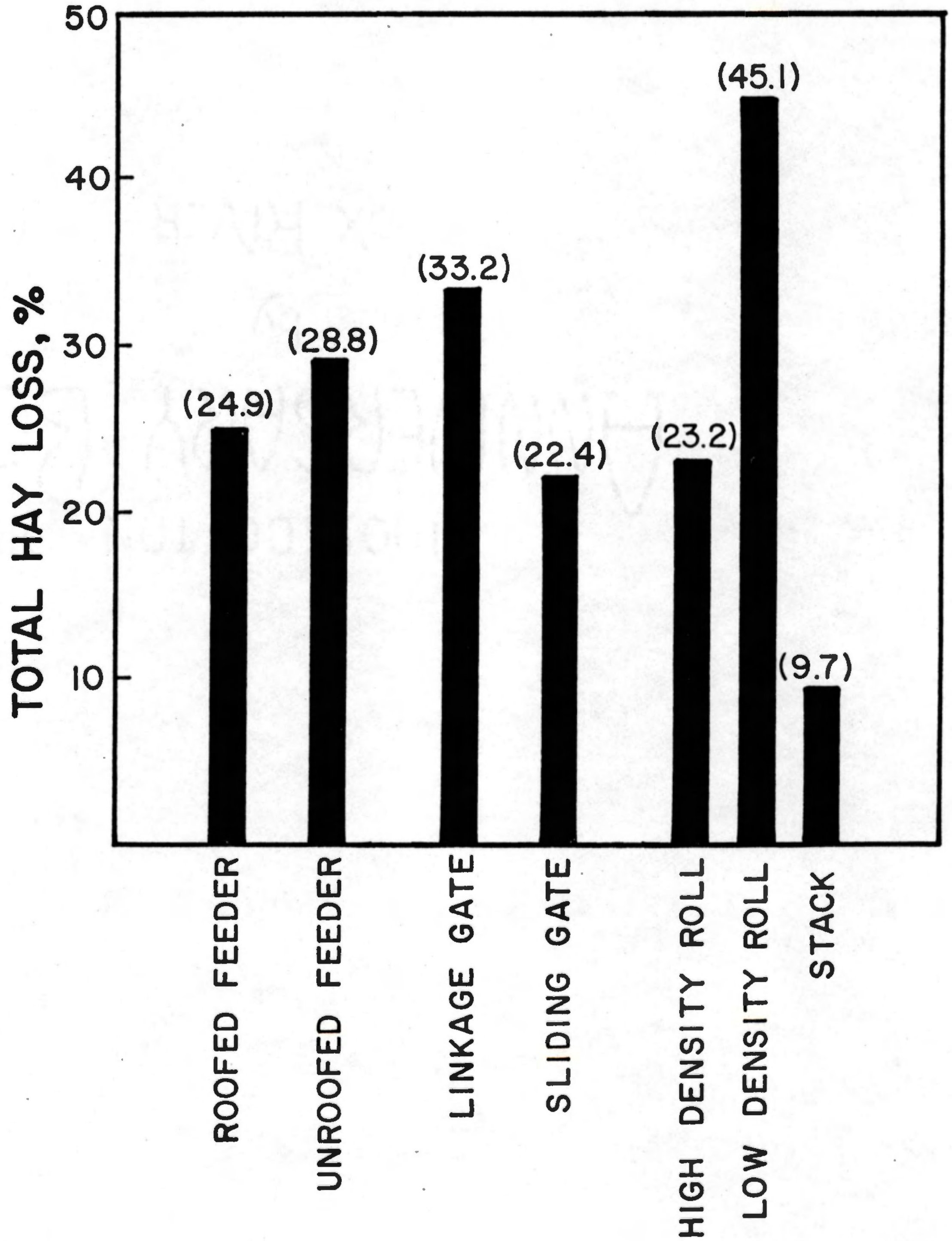


Figure 15. Percentage of total hay wasted classified according to feed bunk type, headgate type, and package type.

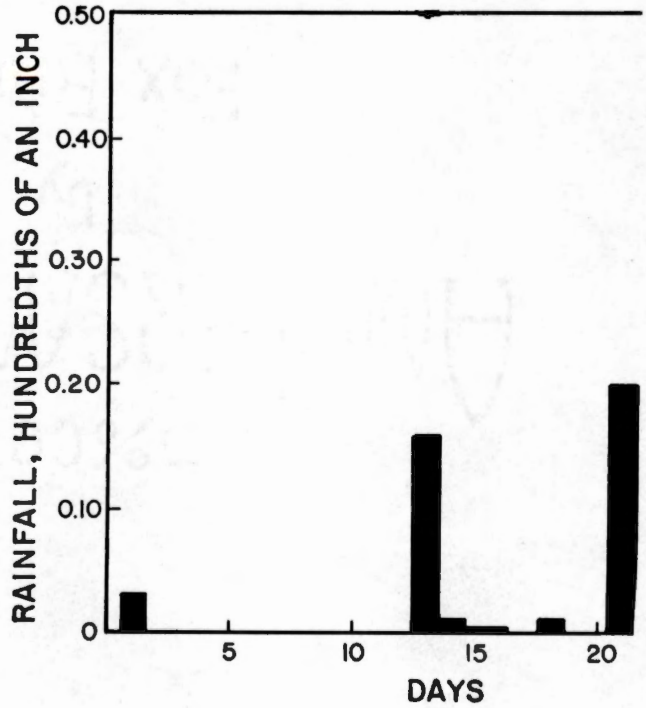


Figure 16. Precipitation record during feeding trial; all precipitation occurred in the form of snow.

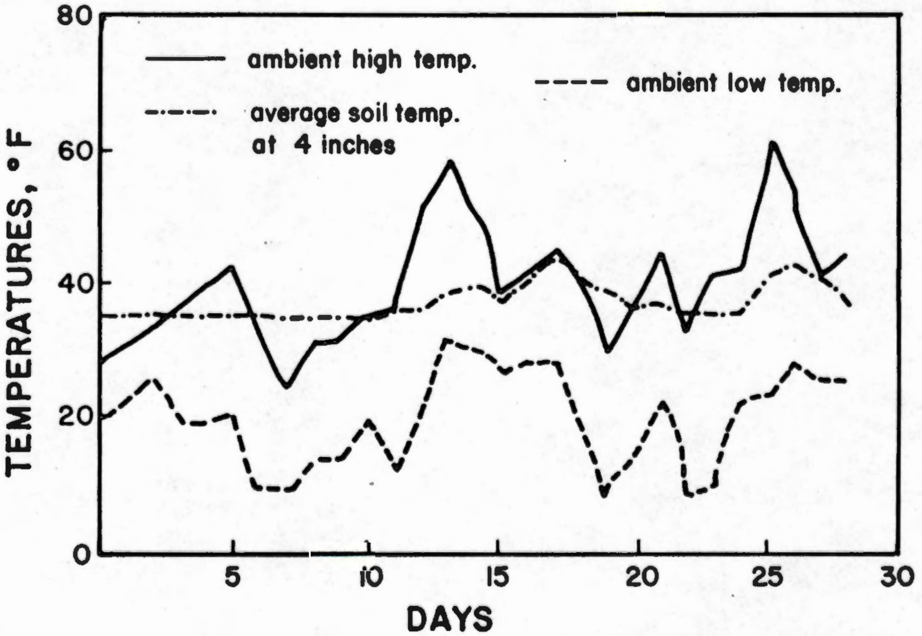


Figure 17. Graph showing high and low ambient temperatures each day of the feeding trial. The average soil temperature at a four-inch depth is considered to approximate internal package temperature and frozen shell temperature.

breaking loose before loading into the hay bunks. The weathered outer surface of the bale remained frozen during feeding. Temperature of the bale was assumed to be approximated by temperature at a depth of four inches (see Figure 17). The frozen shell had to be broken into pieces with axes when the refused hay was removed to be dried. Low-density rolls had a frozen shell extending to greater depth than did high-density rolls or stacks. Cattle could eat little of this frozen, weathered shell. Stacks also were frozen to the ground and were quite difficult to move. The sides of the stacks were not frozen and in good condition, but the tops remained frozen from time feeding until the refused waste was removed.

IV. PACKAGE TYPE INFLUENCES ON LOSS

High-density rolls, low-density rolls, and stacks were fed with trampling loss and refused hay loss being determined for the different package types. The low-density rolls had the most waste while stacks were more fully consumed. The average total loss for stacks was 9.7 percent, compared to 23.2 percent for high-density rolls, and 45.1 percent for low-density rolls (Figure 15, page 43). Refused hay and trampling loss followed the same trend. This is a verification of Robertson's findings done under muddy conditions in 1977 (28).

The refused hay losses were significantly different at the 5 percent level, being 6.6 percent for the stacks, 15.5 percent for the high-density rolls, and 21.3 percent for the low-density rolls. The large loss for the low-density rolls can be attributed to the extensive frozen shell discussed previously and to the generally deeper spoilage depths this package tape exhibits. The stacks seemed more preferred and were more fully consumed than the low-density rolls. The loose hay packing of the stack allowed the cattle to easily obtain a higher quality forage immediately upon feeding; they did not have to work through a frozen shell to get to edible hay.

The trampling loss data showed the low-density rolls were the most wasted. The stacks had a trampling loss of 3.1 percent; the high-density rolls showed a 7.4 percent trampling loss and the low-density rolls had a 23.7 percent trampling loss, Figure 18. The large low-density roll trampling loss can, to some degree, be attributed to the normally high waste associated with this package and also to the cattle's willingness to sort through the low-density package waste before pulling the more densely-packed hay from the high-density rolls. Figure 19 shows a linkage system headgate and the trampling loss associated with the low-density package.

V. RATE OF CONSUMPTION COMPARISON

Daily estimated hay consumption was a visual subjective evaluation of what percentage of each package within each feeder had been consumed. This estimate was made to determine cattle preference for hay package type. The visual estimation was corrected at the end of each feeding period using the original package weight and the refused hay weight to produce the corrected daily estimated hay consumption. The consumption rates are shown in Figures 20 and 21 comparing hay consumption in roofed and unroofed feeders for week number two.

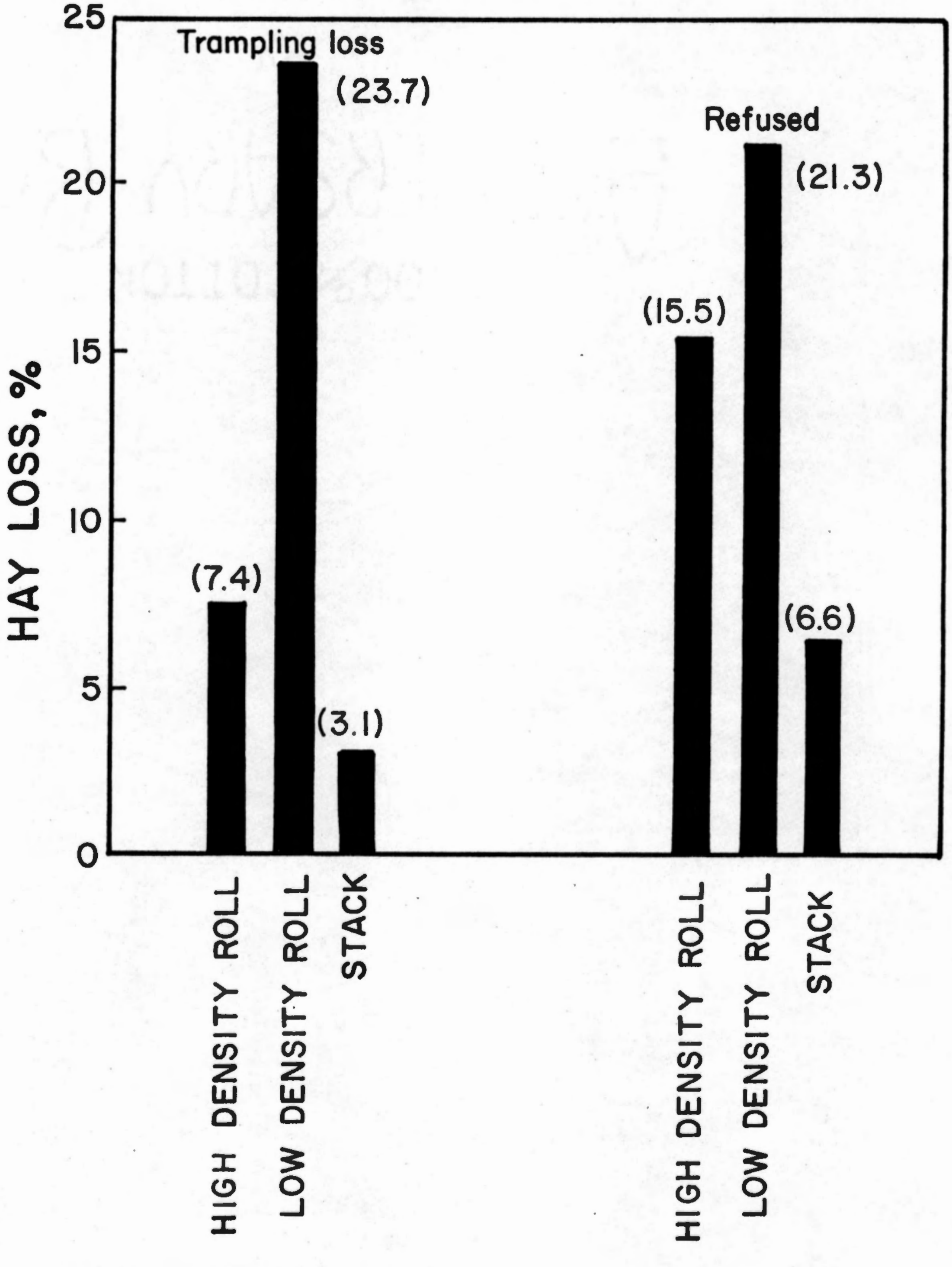


Figure 18. Percentage of each package type trampled into the mud or refused.

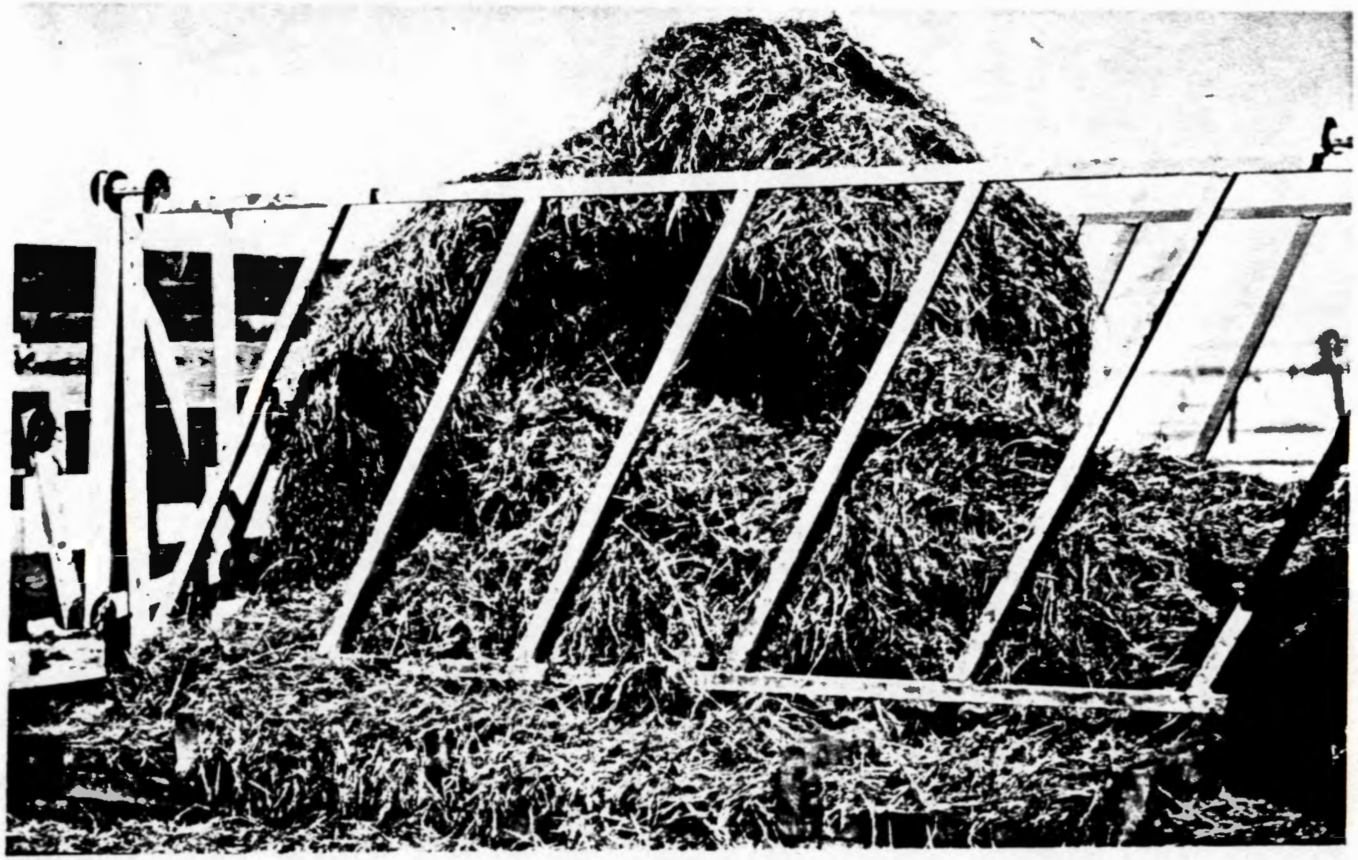


Figure 19. Low-density package in linkage headgate system. Note trampling loss and eating pattern.

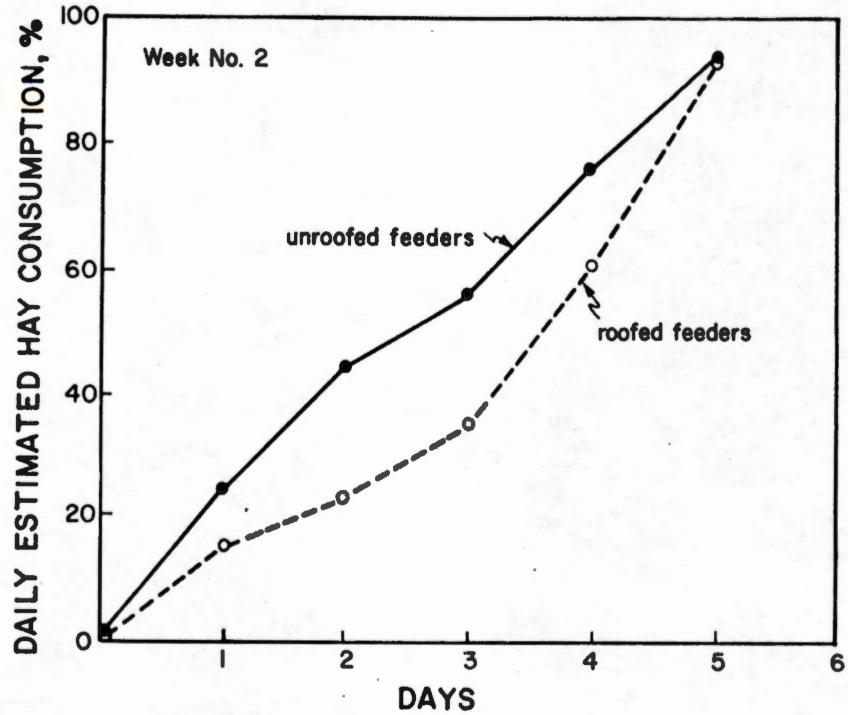


Figure 20. Visual estimation of hay consumption per day in roofed and unroofed feed bunks.

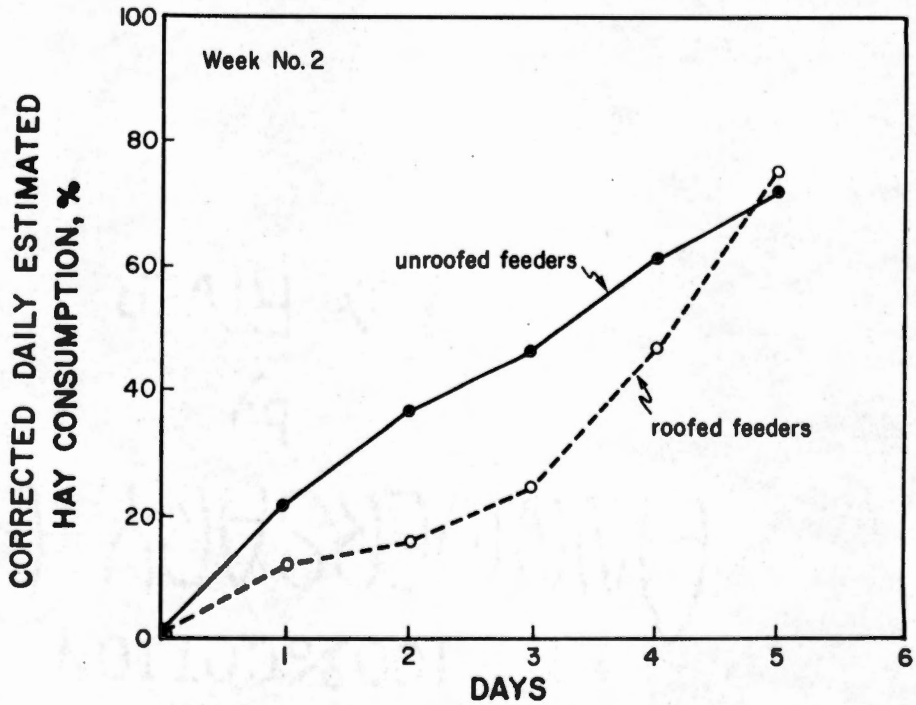


Figure 21. Hay consumption data corrected to agree with weighted total loss data. Note similiarity between the two graphs.

Cattle preferred the hay in the unroofed feeders as shown in both Figures 20 and 21 for week number two. The trend was similar for weeks one and three and can be attributed mainly to the headgate design difference. The roofed feeder headgates, as stated previously, were heavier and tended to limit hay access more than the gates of the unroofed feed bunks. No preference difference was noted between the bunks with sliding or linkage headgate systems. Figure 22 is a summary of these results.

Comparing the different package types, stacks were consumed first, then high-density rolls, and low-density rolls last. The rate of consumption was most consistent with the high-density package. Low-density rolls were the least quickly consumed as well as the least fully consumed. This is a verification of Robertson's work in 1975 (28) (see Figures 23 and 24). Weather conditions producing the frozen thatched shell waste can explain the stack preference and much of the low-density discrimination. The low-density hay packing associated with the stack is a factor in preference. The larger amount of weathered hay in low-density rolls discouraged cattle from eating these packages readily. Figure 18, page 47, shows the losses for package type broken into trampling loss and refused hay.

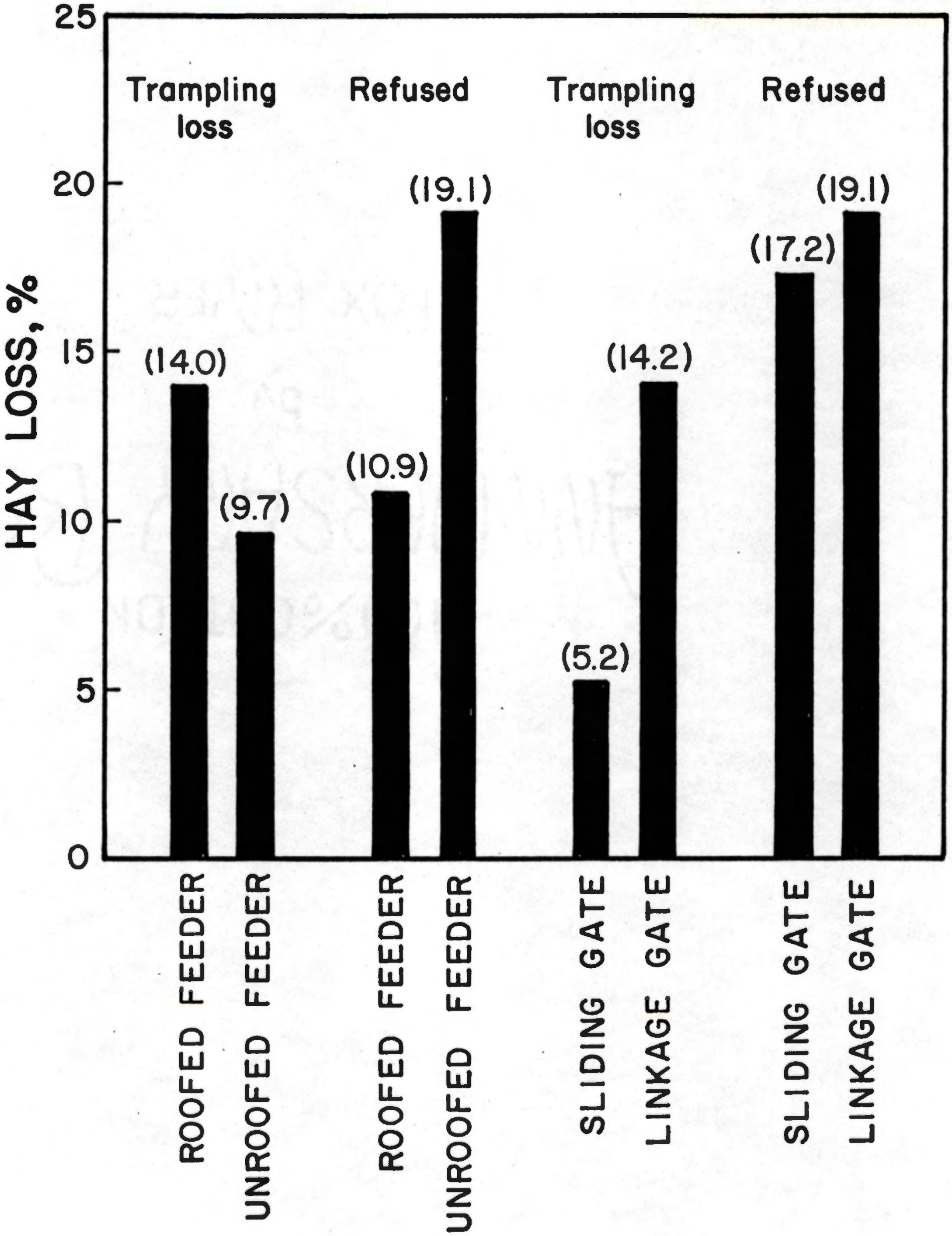


Figure 22. Trampling and refused hay losses for the different feed bunk and headgate designs.

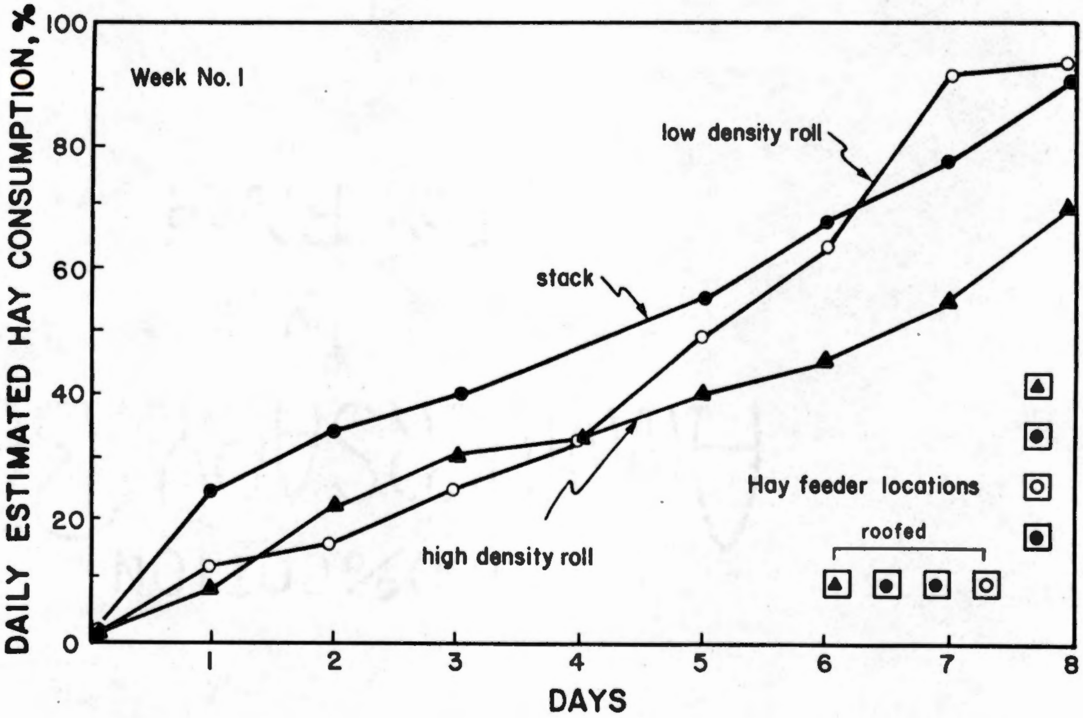


Figure 23. Cumulative consumption of different hay packages for week 1. Note package location and type.

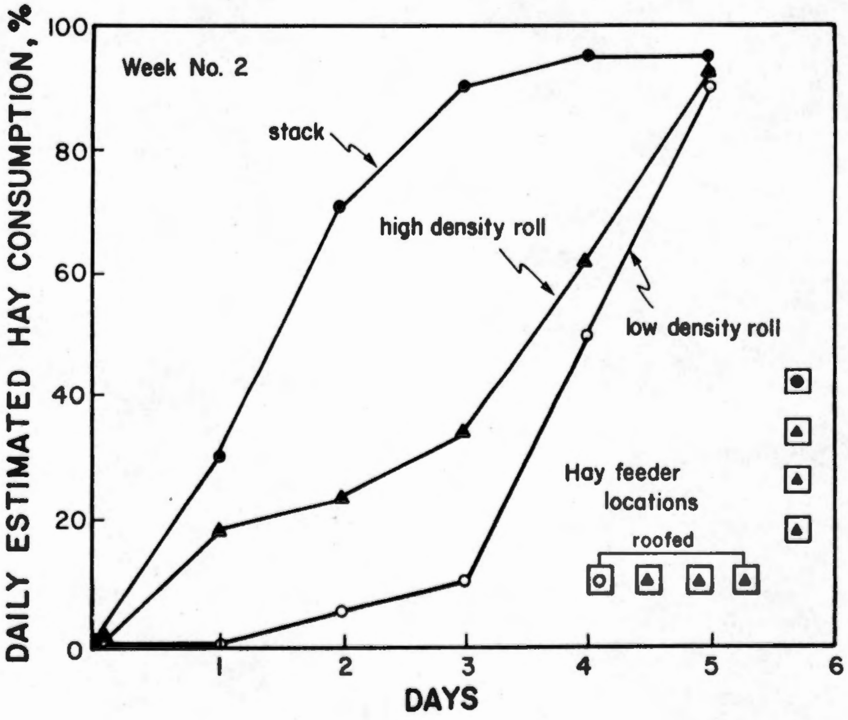


Figure 24. Cumulative consumption of different hay packages for week 2. Note package location and type.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

Roofed and unroofed feed bunks and two metal headgate systems were designed and tested with the objective being to evaluate trampling and refused hay feeding losses. Outside stored stacks, high-density rolls, and low-density rolls of bermudagrass hay were fed randomly in each feeder type during a three-week feeding trial. Hay trampling loss and refusal loss for each feed bunk type, headgate design, and package type were determined. Cattle preference among package types was noted by visually observing the cumulative percentage of each package consumed daily.

The roofed feed bunks had significantly lower refused hay loss both by weight and as a percentage of the original package weight than did unroofed bunks. The presence of a roof over the hay package cut the refusal loss nearly in half. The trampling losses were not significantly different between bunk types.

Two headgate suspension systems were studied in the unroofed feed bunks. The pin-jointed, four-bar, straight-line-motion suspension system and the four-guide, sliding suspension system had similar hay losses. The sliding system, requiring accurate guide alignment, was more difficult to install and maintain and had a tendency to jam periodically. While the linkage system did not jam, a number of problems were encountered. Clip-pin removal by cattle resulted in a detached headgate and free access to hay. Collapse of hay packages, under certain conditions, would push the headgate outward allowing forage to extend over the feed bunk edge onto the ground. This condition then prevented normal inward headgate movement. Both problems appear more easily solved than the jamming-alignment problems presented problems presented by the sliding-gate system.

Of the three package types studied, stacks were the most fully consumed, and low-density rolls were the most wasted. Trampling and refused hay losses were significantly different for the three package types. Cold weather produced a frozen shell around roll packages and produced frozen tops on stacks. The large frozen masses could not be torn apart by cattle and substantially influenced both waste and preference.

Cattle refused less hay in the roofed feeders; for the unroofed feeders, there was no noticeable preference by cattle between headgate suspension systems. With reference to package type, stacks were the most rapidly consumed. Low-density rolls were the least preferred as well as the least fully consumed. High-density packages held a "middle of the road" position (see Figure 24, page 52).

II. CONCLUSIONS

1. Feed bunks with roofs had approximately half as much refused hay loss as the unroofed feed bunks. The trampling losses were similar for the two bunk types.

2. Sliding and linkage headgate suspension system has similar refusal losses. The linkage system had a substantially larger trampling loss because of a number of malfunctions encountered.

3. The sliding headgate suspension system tended to jam whenever cattle applied uneven or off-center pressure to the headgate. Guide alignment also had to be maintained to prevent jamming.

4. Prolonged freezing periods following a significant rainfall resulted in a frozen shell on roll bales and on the top layer of stacks resulting in excessive refusal waste.

5. Stack-type hay packages were consumed most fully, high-density rolls ranked second. Low-density roll packages were the most wasted. Trampling loss and refused hay loss both followed the same trend.

6. Stacks were consumed most rapidly overall. On the average, high-density roll packages were the second most preferred and most consistently consumed. Low-density rolls were the least preferred.

III. RECOMMENDATIONS FOR FURTHER STUDY

The linkage headgate suspension system holds promise for further study. A locking pin clip as well as some method of limiting headgate movement can easily remedy the major problems encountered in this study. These changes should substantially reduce the high trampling loss associated with the system.

New large-package hay feeding methods and new feeder types should be developed. More literature on large package hay feeders needs to be available emphasizing the proper feeding method for each package type.

Also, feeders should be evaluated under a variety of area weather conditions.

Feeders might also be developed around specific package type characteristics. Developing feeders to accommodate a large number of package types reduces the performance for any particular package type. Developing new package types around the feeding method or hay use might also create new insight.

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REFERENCES CITED

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VITA

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