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To the Graduate Council:

I am submitting herewith a thesis written by William Leo Kilgore entitled "Moisture Level Effects on Three Packaging and Handling Systems for Midland Bermudagrass Hay." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

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MOISTURE LEVEL EFFECTS ON THREE PACKAGING AND HANDLING SYSTEMS FOR MIDLAND BERMUDAGRASS HAY

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

William Leo Kilgore

June 1973

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ABSTRACT

Three packaging and handling systems for Midland bermudagrass hay were tested at various moisture levels. A conventional baler with bale thrower and wagon, a roll baler, and a compressed hay stacker were compared on the basis of packaging and handling capacity, field efficiency, packaging material efficiency, and cost per ton of hay. Hay quality data were taken for inside storage of conventional bales and inside and outside storage of roll bales and stacks. Handling operations for the roll bales and stacks were performed by a tractor-mounted, three-point-hitch stack-mover.

Since the drying rates varied for the conditioned and windrowed hay used in the experiment, a wide range (7 to 46 percent) of hay moisture contents for testing the equipment resulted. The conventional bale system was examined at the 7 to 16 percent moisture range only. Packaging capacity in terms of total matter increased linearly with moisture. Since the handling and unloading of the conventional bales from the wagon were done by a one-man operation, the heavier, higher moisture bales resulted in increased unloading time and reduced handling capacity.

The roll baler and stacker were used to package hay with moisture content ranging from 8 to 46 percent and 9 to 42 percent respectively. Packaging capacity (total matter) for the roll baler increased linearly with increased moisture content of the hay. The packaging capacity (total matter) for the stacker increased with moisture content up to

approximately 30 percent moisture; then, it decreased slightly. This decrease was the result of reducing the feeding rate to prevent clogging the pickup discharge duct.

Cost analyses based on the yearly production of 500 tons of hay were performed for each system. Total costs per ton were calculated; these costs included the tractor, machine, and labor costs. A comparison of the conventional bale, roll bale, the stack system at 15, 17, and 16 percent hay moisture contents, respectively, resulted in calculated total costs per ton of $5.03, $4.29, and $3.62. When the roll bale and stack systems were compared at the 20 to 22 percent moisture content range, the roll bale system was the cheaper with a cost of $2.70 per ton, while the stack system cost was $2.87 per ton. A higher moisture content comparison between the roll bale (28 percent) and stack (31 percent) systems resulted in a $2.89 per ton cost for the roll bale system and $3.14 per ton cost for the stack system.

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CHAPTER I

INTRODUCTION

A successful livestock industry must feed large numbers of animals at an acceptable cost and with minimum inputs of labor. Hay is an important livestock feed, but traditional hay-making requires many hours of tedious, physical summer work to bale, load, and transport the hay. Recently, however, the farm equipment industry has taken a probing look into haying practices and has devised machines that may revolutionize hay-making methods.

Hay production for livestock feed is big business in the United States. Its value was ranked third among field crops grown in the nation during 1972, being 3.66 billion dollars (50). Approximately 2 percent of the total national acreage of hay was harvested from 1.37 million acres in Tennessee (19). This acreage was the highest for any major crop in the state (26). Hay is the fourth ranked crop in dollar value in the state, amounting to 50.8 million dollars in 1971 (50). This value increased by 0.4 million dollars in 1972.

With a yearly increase in yield per acre, the hay crop will demand more attention and time unless new machines and techniques are employed to reduce labor and machine cost per ton of hay utilized. The objective of this report was to determine and compare performance characteristics for three hay packaging and handling systems, as affected by hay moisture content. The systems were chosen to be suitable for farms in Tennessee producing 75 acres of hay per year. The three systems studied were the conventional, roll bale, and stack systems. Field capacity (tons of hay processed per hour), field efficiency (ratio of actual to theoretical field capacity), packaging material efficiency (ratio of hay packaged and stored to that available in the windrow), machine operation costs, and hay unit storage properties were examined for each hay-making system. Hay unit internal temperature and change of weight during the curing period were measured for each system. The study was restricted to one hay crop, Midland bermudagrass (Cynodon dactylon (L.) Pers. var. Midland).

CHAPTER II

REVIEW OF LITERATURE

I. LABOR REQUIREMENTS FOR MAKING HAY

The use of hay as a winter feed for livestock is an established practice. When pasture lands are grazed down or covered with snow during the winter months, the herdsman needs only to scatter the appropriate number of bales per animal to supply the required feed. However, man-hours of labor required for this feeding method are high, and increased wage rates have caused these labor requirements to be a critical economic problem in hay-making.

In 1960 Hodges and Esmay (27) studied human energy requirements for handling hay and straw. The variables of importance in lifting and stacking the bales were bale weight, speed of handling, and height of lifting. In this study it was determined that five bales per minute is a handling rate than can be steadily maintained, and eight bales per minute can be easily maintained for short periods of time. More pounds of material could be handled per minute for conventional bales weighing 45 pounds than for bales weighing 65 pounds when stacking above a 15-inch lifting height. Less energy expenditure was required for the lighter bale.

In 1967 Ferguson et al. (14) made a study of labor used in harvesting. They discovered that 96 percent of the harvested tonnage of hay in Tennessee was in the form of conventional bales, 5 percent of the tonnage was field loaded by a bale thrower, and only 4 percent of the tonnage was stored in stacks of long loose hay. At that time, the bale thrower mounted on a conventional baler was the most economical method of packaging and field loading hay and required the lowest number of man-hours per acre (1.43). Floyd (15) reported the labor required to harvest the 1967 crop of 126.3 million tons of hay averaged 1.5 man-hours per ton. Cockrel (6) said that the lack of labor to handle hay in bales had been a limiting factor in producing hay in Tennessee.

Management will be forced to seek ways to achieve maximum production efficiency for the total haying system due to a severe shortage of reliable labor and the increasing cost for skilled farm labor. Rider and Bowers (48) determined labor requirements for packaging and handling hay by three systems. The one-ton stack system was reported as the lowest in man-hour demand (0.9 man-hours per ton), followed by the roll bale system (1.3 man-hours per ton), and the traditional bale system without bale thrower (2.5 man-hours per ton).

Regardless of the type of haying system used, the machine operator has an important effect on capacity. Bargen (1) indicated that performance of a haying machine depends on the man-machine combination. Barnes (2) and Harrison (22) also noted the significance of an alert, trained operator in maximizing machine capacity.

II. OPERATING CAPABILITIES OF CURRENT TYPES OF HARVESTING MACHINES

The threat of an afternoon shower is a fear known to all hay producers. Von Bargen (51) emphasized the importance of weather probability information for successful hay harvest, and presented data on the number and length of periods of consecutive open haying days without rain. These data were declared to be extremely valuable in determining the operating capability of a hay harvesting system. The timeliness involved in hay-making is very critical indeed. Jeffers and Staley (30) indicated that the required haying machine size varied directly with the acreage and inversely with the consecutive days available for hay making.

The popularity of packaging hay in conventional bales grew from 80 percent in 1964 to 90 percent in 1967. Zimmerman (57) explained this growth in popularity as a function of the high field capacity of the baler and of the desirability of having packaged bales to be sold and transported from the farm conveniently. In 1963 Hofmeister (28) reported a major breakthrough in hay baling operation--the advent of the bale thrower, permitting random loading of bales into a trailing wagon. This system reduced the labor requirement approximately 33 percent without reducing the baling capacity. In baling 10 to 20 percent moisture field-cured hay, the baler with bale thrower had a capacity of 6.45 tons per hour according to Hofmeister (28). In a more recent study, Larsen (31) observed PTO baler speeds of 2.17 to 5.58 miles per hour and actual capacities of 6.06 to 13.20 tons per hour. The high baling capacities were recorded when balers were powered by tractors of 60 to 100 horsepower.

Whitney (54) reported that field losses from conventional baling were a problem of growing importance. Field losses consist of that hay which remains on the ground. Failure to pick up this hay is a deficiency of mechanical components of the system. The total field losses for a baler with bale thrower ranged from 1.7 to 4.8 percent of the hay available in the windrow.

Field material losses were also explained by Dobie et al. (11). They included shatter of the hay as it enters the pickup attachment and handling losses prior to weighing as field losses. They determined that packaging hay at a low moisture content increased the losses.

A more recently devised haying machine is the roll baler. Haverdink and Buchele (23) at Iowa State University designed the original giant roll baler. This one-man baling system produced twine wrapped rolls of hay on a large spindle. A subsequent design was reported by Floyd (17) to package roll bales weighing 1,000 to 1,500 pounds. This baler rolled the hay on the ground to form a bale 7 feet long and 3 to 6 feet in diameter without lifting the rolled bale. Unloading was accomplished by hydraulically lifting the tailgate and leaving the bale stationary while the baler moved forward.

In 1958 Martin (33) described the use of the hay cage for molding a hay stack to a desirable size and shape. This system was still another innovation in hay handling. The handling of the loads consisted of three phases: loading, traveling, and unloading. This system displayed a high degree of versatility and probably accrued the lowest cost per ton of any known hay handling system at the time. In 1969 Yost (56) proposed that the loose hay stack system represented a one-man-machine combination offering labor reductions. With the modernized stacking wagon, one man could pick up hay from the windrow, form a hay stack, and place it as desired.

However, in 1971 Floyd (16) reported capacities were decreased for the stack system when windrows contained slugs of green hay and when windrows were short and uneven. The stacks also were noted not to push out of the wagon cleanly when operating in short, second-crop cuttings. This same effect when stacking high moisture hay was observed by Larsen (31).

III. HAY MACHINE PERFORMANCE INDICATORS

The amount of hay processed in a given time by a machine is called the field capacity of the machine. According to Bowers (4), field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed as a percentage. The effective field capacity is the actual rate of performance based upon total field time. The theoretical field capacity in acres per hour is the rate of performance obtained if the machine performed its function 100 percent of the time at the rated operating speed and utilized the maximum rated width. Bowers (4) and Hunt (29) list field efficiencies for balers as 65 to 80 percent at operating speeds of 1.5 to 4.6 miles per hour. Field efficiencies for the stack maker and roll baler have not been reported in the literature.

For all three systems, the field machine index is a good indicator of the effect of short, uneven windrows on machine capacity. Renoll (45) defines the field machine index as the ratio of the actual field production time to production time plus row-end turning time. A low index indicates excessive machine turning time that decreases the field capacity. Another effect on capacity is explained by Glover (20) as nonoperating time or down-time. This is time spent for adjusting the machine in the field, for unclogging implements, and for rest stops by the operator.

Harrison (22) pointed out that the maximum capacity for balers is reached only under ideal conditions, such as with a uniform size of windrow. These conditions are rarely obtained in practice. The power output and mechanical features of the tractor must also affect maximum capacity.

IV. ECONOMIC ANALYSES

Fairbanks et al. (12) explained that higher labor costs, higher machinery prices, and lower farm-product prices have cut sharply into farm profits. Thus in hay making, economic considerations must include timeliness, quality of work, ownership costs, and operational costs.

Petritz and Carson (43) conducted a study comparing a standard baler and bale thrower, a large round baler, and a hydraulic stack wagon (1 ton). The cost analyses were based on a 4 ton per hour harvesting capacity, excluded tractor cost, and included a labor cost of $3.00 per hour. The roll bale and stack systems required only one man while the conventional system required three men. A 500-ton per year production level was reported to cost $5.54 per ton for the conventional system, $3.69 per ton for the roll bale system, and $3.53 per ton for the stack system. The cost per ton included packaging and handling expenses. There was no mention of hay moisture or its effect on baling. If the production level was less than 100 tons annually, custom handling was recommended.

Renoll et al. (47) reported that the 3-ton stack handling system was lower in cost per ton than a conventional bale system which used a self-propelled loader or a tractor-pulled loader hauling 119 bales and 55 bales respectively. This comparison of a bale and stack system was based on a transport distance of one mile from the windrow to storage area. Renoll et al. (46) explained the higher cost per ton for the conventional bale system resulted from the higher machinery investments required.

The Tennessee Crop Summary for 1972 (50) valued the Tennessee hay crop (including all types of hay) at $28.50 per ton and the national value per ton at $39.20. Deterling (10) reported the cost of harvesting and handling hay in the Southwest to be one-third to one-half of the total value of the packaged hay. The cost of mowing, conditioning, raking, baling, and hauling hay was approximately $16.00 per ton in Tennessee (7).

V. MOISTURE EFFECTS ON HAY

When the goal is economic scheduling of field operations and maximum economic return, baling hay at high moisture content becomes increasingly important. The formation of high density packages of high moisture hay is desirable because it results in low field losses. Shatter of leaves from the hay stems is also reduced. Preventing shatter of the nutritious green leaves is essential for maintaining the carotene content. Carotene is the precursor of vitamin A and the best single criterion of quality in hay (3). Nelson (38) points out that high moisture hay is suited to transporting, handling, and storing.

He found that although retention of gross energy during storage decreased with increased moisture content of hay, dry matter losses were reduced. Additional research by Nelson (39) suggests that the internal heat of baled hay during storage increases with both increased moisture content and density. Problems associated with high moisture content hay are mold, dust at feeding time, and deterioration of twine.

After harvesting, respiration continued with the formation of carbon dioxide since plants are alive for a short time after cutting. Watson (52) explained that the main changes in hay during curing are due to respiration but that bacterial action also occurs. Wood and Parker (55) stated that respiration was a major source of heat energy for drying in most barn hay drying systems. The microbiological oxidation of hay was reported by Miller (34) to be capable of developing considerable heat in the hay during storage, resulting in the destruction of dry matter. Watson (52) reported that carotene is readily oxidized, thus is susceptible to losing its nutritional value for cattle. The most highly digestible nutrients are oxidized first. The rate of oxidation is increased by high temperature, high moisture content of the hay, and by the photochemical action of the sun.

Weeks et al. (53) reported that alfalfa hay baled and stacked at 40 percent moisture content (W.B.) reached the highest temperature within 5 to 10 days after baling. Of the two hay packaging systems tested, the conventional bales reached 154° F while the 6-ton stacks reached 145° F. The stacks reached higher temperatures more slowly but retained the heat for a longer period of time. The temperature difference between bales and stacks was attributed to the difference in dry matter density, which was 12.3 and 4.6 pounds per cubic foot for bales and stacks, respectively. Two physical problems with high moisture hay were bale deformation and stack collapse. Mold formation was observed in stack core samples from the 40 percent moisture hay. The 30 to 33 percent moisture hay retained color very well. Temperatures were in the range of 100 to 110° F for 25 percent moisture content stacks.

Parsons (41) calculated the standard bale total matter density to be 8 to 12 pounds per cubic foot, the giant roll bale (Hawk Bilt) density to be 6.1, and that of the one ton stack to be 5.6 pounds per cubic foot.

The effect of increasing the density of stacks for alfalfa hay was summarized by Weeks et al. (53) in the following statements:

1. Increasing the density reduces the oxygen movement which decreases microorganism activity and resulting dry matter loss.
2. It causes faster rise of internal temperature which increases rapid drying to moistures below microorganism activity level.
3. It produces a high temperature which destroys many microorganisms.

Calves fed alfalfa hay baled at 35.2 percent moisture content have performed as well as those fed alfalfa hay baled at 26.2 percent moisture content (W.B.) according to Miller et al. (35). This would indicate the possibility that good nutritive value at moisture contents higher than usual can be maintained. A study at Auburn University by Renoll et al. (46) indicated the suitability of 24 percent moisture 3-ton johnsongrass stacks as feed for beef cattle. These stacks were stored outdoors and sustained little weather damage. A one-foot space around all stacks and roll bales to minimize losses due to storage was recommended by Smith (49).

VI. MIDLAND BERMUDAGRASS HAY

Midland bermudagrass (Cynodon dactylon (L.) Pers. var. Midland) is a hybrid produced by a cross between Indiana common and Coastal bermudagrass and is more winter hardy than Coastal. It is two to four times as productive as the common strains of bermudagrass on fertile soils. Decker et al. (9) described Midland bermudagrass as a tall, leafy grass producing a more open sod than common bermudagrass and well suited for the environment along the northern edge of the bermudagrass belt where Coastal does not adapt as well. In order to insure the high quality of the hay crop, one extra harvest per season is required. The extra harvest increases yield by only 5 to 10 percent.

Midland bermudagrass is suited to the cooler winters of higher altitudes. Fribourg (18) determined that Midland bermudagrass was capable of surviving at elevations up to 1,500 feet in Tennessee. Midland bermudagrass also has the ability to withstand hot summer temperatures in Tennessee. Burns (5) advised that Midland bermudagrass be cut in the spring when 15 to 18 inches tall, with subsequent cuttings three to four weeks apart. Excessive maturity toughens and lowers the hay quality.

CHAPTER III

PROCEDURE

I. DESCRIPTION OF MACHINES TESTED

Hay harvesting machines used in this experiment were a conventional baler, a roll baler, and a stacker.

The conventional baler used was an economy model machine with bale thrower and trailed wagon. Shown in Figure 1, it was a New Holland Model 273 baler with a No. 54A PTO-driven bale thrower. Bale length and density were adjusted to give a bale weight of approximately 50 pounds. The average wagon load of bales weighed 1.5 tons. Rear to front loading of the wagon was accomplished by conrolling the discharge trajectory of the bale thrower from the tractor seat.

The roll baler used to form large round bales is shown in Figure 2. It was a Hawk Bilt Model 480 baler which rolled hay forward on the ground to form a six foot diameter by seven foot long bale weighing approximately one-half ton. Bale density was controlled by the combination of the raddle chain speed and tractor forward speed. The roll of hay formed was not bound by twine or transported in the machine after completion of the bale. When the roll bale was of satisfactory size, the operator raised the tailgate of the baler and moved the machine forward leaving the bale behind.

The loose hay stacker used was the Hesston StakHand No. 10. This machine formed a compressed stack seven feet wide by eight feet long by eight feet high. Operation of the stacker in the field is shown in

Figure 1. Conventional baler packaging and throwing bales of hay into a trailed wagon.

Figure 2. Roll baler packaging a bale of hay.

Figure 3. Hay was drawn pneumatically from the windrow by the rotating paddles of the pickup assembly and blown into the bale chamber. When the chamber was filled, a canopy was moved down hydraulically to compress the layer of hay. Flow of hay into the forward or rear part of the bale chamber was controlled by a deflector attached to the front upper area of the compression canopy. Control of hay position within the chamber was necessary to obtain compressed layers of uniform thickness to give a well formed stack. Unloading the one-ton stack was executed by opening the tailgate, activating an unloading floor chain and, at the same time, driving the tractor forward. As with the roll baler, the bale was left behind.

II. FIELD HARVEST OF HAY

Four Midland bermudagrass fields were available for experimental plots: a 3.6-acre rectangular field, an 8.0-acre rectangular field, an 8.0-acre trapezoidal field, and a 9.2-acre "dumbbell" shaped field. The 8.0-acre trapezoidal field and 9.2-acre "dumbbell" shaped field were the primary plots for testing the three machines. The 3.6-acre rectangular field and the 8.0-acre rectangular field served as auxiliary plots for additional experimental units in case of weather damage to hay on the primary fields.

Original plans were to bale at two moisture levels--25 percent (W.B.), with all three packaging machines operating simultaneously on alternate windrows; and 35 percent, with only the stacker and roll baler used simultaneously on alternate windrows. Thus, one field was designated as the low-moisture field, and the other as the high-moisture

Figure 3. Stacker unloading to complete the packaging process.

field. The fields were alternated as low and high moisture sources for successive cuttings.

The order in which the machines were operated in the field was determined by observing speeds during practice trials. The tractor was offset to the left side of the roll baler, which prevented it's passing another machine on an adjacent windrow to the left. Practice runs, made in baling a field of tall fescue-johnsongrass (*Festuca arundinacea* L.; *Sorghum halepense* (L.) Pers.) hay, were used to experience machine operators on harvesting techniques as given in the manufacturers' instruction manuals. Each operator was instructed to run his machine at its highest capacity in baling the bermudagrass hay.

The hay was cut, conditioned, and windrowed with a New Holland Model 467 Haybine which had a seven foot cutting width. The hay was field dried in the windrow. The extent of drying was measured by a calibrated rapid determination moisture meter. When the hay was at the desired moisture level, two windrows were raked together by a pull-type John Deere Model 640 side delivery rake, forming one large windrow including hay from a 14-foot swath. Prior to and during harvesting operations, samples of hay were collected to determine the true average moisture content of the packaged hay from each machine. The standard oven-drying method was used to determine the moisture content in percent (wet basis).

The Midland bermudagrass hay was cut when 15 to 18 inches tall or six weeks after the preceding cutting, whichever came first, for cuttings subsequent to the initial one on June 13. The second cutting was made on July 21, and the third, on September 7. Operational mistakes and rain resulted in a shortage of experimental units of high moisture hay for the first cutting. The 3.6-acre reserve plot was used to provide additional experimental units of hay. During the second cutting of low moisture hay, additional capacity checks on the conventional baler were made on the 8.0-acre rectangular plot.

Time and motion studies were made of operations to package each experimental unit of hay. The stacks and roll bales were discharged at the point of completion in the field. Spare wagons for the conventional bale system were positioned at the end of the field where the baler was expected to complete a wagon load of bales. The filled wagon was left at the place in the field where the empty wagon was connected to the baler. After each packaging cycle, the experimental units were tagged for later identification.

Average travel speeds for each machine were timed for a 100-foot distance. During the harvest operation, machine windrow losses from each machine were gathered and weighed. These random samples were oven-dried for moisture level data.

III. MOVEMENT AND STORAGE OF EXPERIMENTAL UNITS

Average geometric dimensions for each roll and stack were measured before moving them to the storage barn or stack yard. Remnant losses resulting from picking up the completed units for transport were weighed. Then time and motion studies were made of operations to load, transport, and position the experimental units for storage. The average handling distance from the field to the storage area was six-tenths of a mile.

The wagon-loads of conventional bales were transported to the storage barn and weighed on portable field scales using proving rings as load sensors. Experimental units of conventional bales weighed approximately 1.5 tons. Randomly selected individual bales were weighed by hand scales and measured for average geometric dimensions. The tractor operator backed the loaded wagon into the storage barn and unloaded and stacked the bales at the designated location by hand. The empty wagon was then weighed as shown in Figure 4 and returned to the field to complete the transporting cycle.

A Hesston No. 10 Stakmover mounted on a tractor three-point hitch was used to transport the roll bales to the storage barn. The stackmover hood was adjusted to handle the smaller roll bales. Loading and transporting each experimental unit to the portable field scales were done, if possible, the day after baling. This one-day waiting period allowed the roll bale to settle and adhere into a denser package more suitable for transport. Figure 5 shows a roll bale being weighed at the storage barn. Experimental units similar to the illustrated bale weighed approximately one-half ton. After weighing, the roll bales were positioned in the stack yard or storage barn. The tractor and empty stackmover were weighed about every third round for tare weight data.

The stacks were transported to the storage area with the same tractor and stackmover that were used for the roll bales, except that the stackmover hood was adjusted for the larger stacks. If possible, handling of the stacks was performed on the day after baling to allow

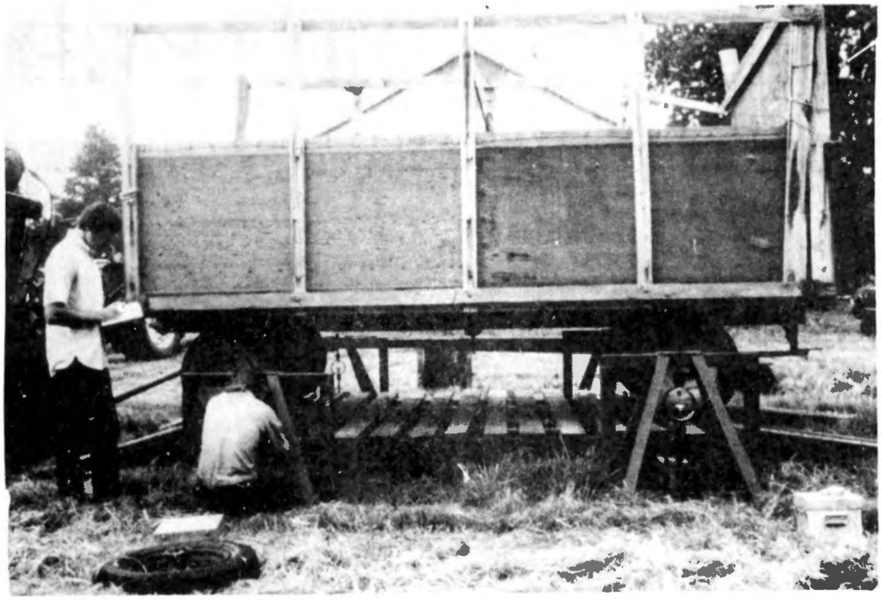

Figure 4. Empty hay wagon being weighed on portable field scales.

Figure 5. Roll bale handled by tractor-stackmover combination and weighed on portable field scales.

the settling and bonding action to occur. The stacks were weighed at the stack yard as shown in Figure 6. Each stack comprised one experimental unit and contained about one ton of hay. After the stacks were unloaded in the stack yard or storage barn, the tractor and empty stackmover were weighed, usually every third round.

Thermocouples were located in the center of two experimental units packaged by each machine system for both the low and high moisture hay. A 24-point recording potentiometer with voltage regulator was used to collect temperature data every three hours throughout the curing period of four to six weeks. For the first and second hay cuts, inside and outside stored hay package internal temperatures were recorded for both low and high moisture experimental units. Conventional bales were not stored outside nor baled with high moisture content hay. Temperature data were collected for conventional bales from all three cuttings.

Some roll bale and stack experimental units stored outside were placed on wooden pallets. One experimental unit for each system at low and high moisture levels was weighed periodically, using proving rings suspended from metal tripods and connected to brackets on the wood pallet. Weighing was accomplished once every two to four weeks for a one- to six-month period. Total weight change determinations were made for roll bale and stack experimental units from the first and second hay cuts. Weight change of a group of conventional bales comprising one experimental unit and stored inside was measured at varying intervals ranging from one to six months. Weight change determinations were made for conventional bales following all three cuttings.

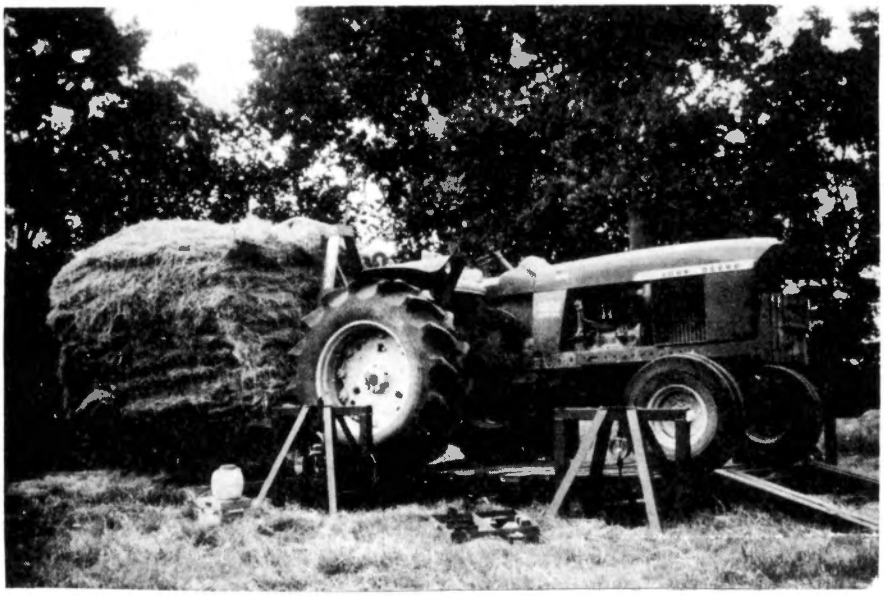

Figure 6. Stack handled by tractor-stackmover combination and weighed on portable field scales.

IV. STATISTICAL AND COST ANALYSES

Regression analyses and simple statistics were calculated for the packaging and handling field data using the SAS (Statistical Analysis System) computer program package developed by the Statistics Department at North Carolina State University. The two-tailed t-test was used to compare the means of small samples with an unequal number of observations according to the procedure explained by Hayes (24).

Cost analyses of packaging and handling operations for a production of 500 tons per year were made. The tractor purchase price was based on a mean value of $105.00 per PTO horsepower as given by Bowers (4), with additional costs for extras such as a dual hydraulic system and additional frond end weights when the system needed them. The freight charge and state sales tax of one percent were included also. Machine purchase prices consisted of the factory F.O.B price, freight charge to the Tennessee area, and state sales tax on the purchase.

The cost calculation method outlined by Glover (20) for cotton production was easily adapted to hay machinery. The ownership costs were the machinery costs considered as fixed and included depreciation, interest on the investment in machinery, housing, and insurance. The straight-line method was used to determine what is considered the largest fixed farm machinery cost item--depreciation. Straight-line depreciation is computed by subtracting the salvage value from the new cost and dividing the remainder by the machine's useful life. Salvage value was computed as 10 percent of purchase price for each machine. Ray and Walch (44) provided the useful life in years for each machine.

According to Glover (20), interest was 7 percent per annum on the average investment for each machine. The average investment for each implement was computed by adding the purchase price to salvage value and dividing by two. Housing cost was calculated as 10 cents per square foot of floor space required for each machine. Insurance was calculated on two-thirds the value of machinery as $0.90 per $100.00 per year.

The operational costs included the variable cost expenditures for fuel, lubrication, repairs, twine (if needed), and labor. The Nebraska Tractor Test Data for 1972 (37) listed fuel consumption to be an average of 3.65 gallons per hour for 60 horsepower tractors. Bowers (4) listed mean fuel cost as 16 cents per gallon and lubrication and oil consumption cost as 15 percent of tractor fuel cost. The machinery lubrication cost of 0.2 percent of the purchase price was used according to the recommendation of Larsen et al. (32). References to Hunt (29) for repair and maintenance percentages of purchase price for the tractor (0.012), baler or stacker (0.031), and wagon or stack-mover (0.018) were made. Also, Hunt (29) listed the weight of twine per ton of hay to be 3 pounds (average). The annual average hourly farm wage rate without board and room in the United States was approximately $2.00 per hour according to Farm Labor (13).

A brief survey, conducted in the Knoxville, Tennessee, area, determined the applicability of Bower's (4) recommendation for the man value of tractor fuel. The results of this survey, 16 cents per gallon of fuel, were consistent with values listed by Bowers. John H. Morrow (36), of Blount-Knox Tractor Inc., quoted a seasonal average of 15 cents per pound for standard baling twine as the mean price for the Tennessee area.

CHAPTER IV

RESULTS AND DISCUSSION

I. MACHINE OPERATING CHARACTERISTICS WITH MIDLAND BERMUDAGRASS HAY

The moisture level of Midland bermudagrass hay had a greater effect on the machine operating characteristics than did shape of field, size of bale, or operator skill. But this variable was difficult to control or measure in the field. Infestations of johnsongrass in the 9.2-acre field further complicated the scheduling of hay with a given moisture content. Drying rates of the hay varied from windrow to windrow. Consequently, it was not possible to bale at just the two moisture levels of 25 and 35 percent originally planned. The moisture ranges of hay packaged by the three systems were: conventional baler, 7.2 to 15.7 percent; roll baler, 7.6 to 46.5 percent; and stacker, 8.9 to 41.5 percent.

Structural properties of the bermudagrass hay influenced the performance of each machine. The bermudagrass hay leaves were slick and springy in mass, and the length of the leaf was an important consideration. Leaves less than 10 inches in length would not interlock to hold together well in a package. This effect was more noticeable with the roll baler and stacker than with the conventional baler.

Bale density affected the package characteristics of conventional bales of bermudagrass hay. With the standard bale cross-sectional size of 14 inches in height and 18 inches in width, a 50-pound bale was desired. To attain this weight, the bale length was adjusted to 39 inches, then to 32 inches, and finally to 30 inches. The longer bales of 39 inches were of low density (6.4 pounds per cubic foot) and tended to buckle and come apart when handled. By adjusting the bale chamber tension device, high density, short bales were made. These were easy to handle without danger of their coming apart. Only data taken in making these short, dense bales were used in calculating packaging capacity for the conventional baler.

Length of the bermudagrass leaves affected the rolling characteristics of the roll baler. The shorter hay was more difficult to form into rolls that held together. Hay leaves of 15 inches or more held together well and bonded into stable rolls. Hay moisture content above 16.8 percent increased the compactness and uniformity of the roll bales.

The leaf length also had an effect on the performance of the stacker. The shorter, 10-inch leaves did not compress as well in the compression chamber as the 15- to 18-inch leaves did. Very little interlocking action occurred among leaves of the shorter, lower moisture content hay. If a weaving pattern in driving the tractor along the windrow were not followed to place the hay in a uniform layer across the stack chamber and if the deflected flow of hay in the compression chamber were not carefully controlled to form a uniform layer of hay from back to front in the chamber, the possibility was always present that the top portion of the stack would slide off the base portion during unloading or handling operations.

The conventional baler and the stacker were sufficiently maneuverable to readily follow windrow contours of irregular shaped fields. The trailing wagon attached to the conventional baler with bale thrower did not require the extra turning space that the roll baler did when alternate windrows were baled. The roll baler required a larger turning radius and was less adapted for use on irregularly shaped fields. Making a 180-degree turn at the end of a windrow with a bale in the roll baler chamber was difficult. The roll of hay tended to lose its integrity and shape when held in the chamber during a tight, row-end turn. These characteristics were reflected by differences in the field machine indexes calculated for the different machine-field combinations as summarized in Table 1.

Of the three machines, the roll baler offered the highest degree of operator comfort and freedom from dust and chaff. The roll baler required minimum control of machine operations since the raddle chain speed and the tractor ground speed were the only variables to monitor and adjust. It was necessary to drive the tractor along the windrow in a weaving pattern to form a roll of uniform diameter along its length. Operator comfort was favorable with the conventional baler also. However, the operator had to contend with the added responsibility of having a variable speed adjustment for the bale thrower. The most demanding machine to operate of the three was the stacker. Dust and chaff created by the pickup blower air stream were very uncomfortable for the operator. Extra concentration and awareness of hay flow into the machine were necessary to operate the stacker. The operator was

Table 1. Machine and Hay Moisture Content Effects on Hay Package Density and Dimensions

	MOISTURE CONTENT	FIELD SHAPE	FIELD* MACHINE INDEX	HAY PACKAGE DENSITY	HAY PACKAGE AVERAGE DIMENSIONS
	%		%	lb/ft^3	H x W x L (in inches)
Conventional baler	7.2	Trapezoidal	86.4	9.6	14 x 18 x 30
	15.3	Trapezoidal	94.7	11.2	14 x 18 x 32
	15.7	Dumbbell	89.6	6.4	14 x 18 x 39
					Dia. x L (in feet)
Roll baler	7.6	Trapezoidal	85.9	4.8	4.7 x 7.0
	12.2	Rectangular	86.1	5.3	4.3 x 7.3
	16.8	Dumbbell	77.8	5.2	4.4 x 7.3
	20.5	Dumbbell	88.1	6.6	5.5 x 7.2
	27.5	Trapezoidal	79.9	7.8	5.5 x 7.0
	31.2	Trapezoidal	80.2	12.1	3.9 x 7.6
	46.5	Dumbbell	91.9	11.7	5.2 x 7.2
					H x W x L (in feet)
Stacker	8.9	Trapezoidal	88.8	4.1	7.1 x 6.1 x 8.6
	12.7	Rectangular	89.6	5.2	6.8 x 6.2 x 8.4
	16.2	Dumbbell	88.9	4.4	6.8 x 6.8 x 8.6
	21.6	Dumbbell	88.1	4.9	7.0 x 6.4 x 8.8
	30.6	Trapezoidal	81.2	6.0	6.9 x 7.6 x 8.6
	41.5	Dumbbell	86.8	6.5	7.0 x 7.0 x 8.6

*Field machine index (percent) is the ratio of productive field time (packaging) to productive field time (packaging) plus turning time.

responsible not only for the weaving action along the windrow but also for control of the canopy deflector position which was changed by raising or lowering of the canopy top.

II. PACKAGING FIELD CAPACITIES AND EFFICIENCIES

The packaging field capacities of all three machines were analyzed for all hay units packaged, with the exception of the 15.7-percent moisture hay made with the conventional baler. At this moisture content, the bale chamber tension adjustment was incorrect, which resulted in the density of the bales being too low. As a result, packaging capacity was greatly reduced. Polynomial regression analyses for field capacity versus hay moisture content were performed for each machine. Although variations in measured capacity values at any given moisture content were high, overall results are summarized in Figure 7. Mean values observed at different moisture contents were plotted. The curves were determined through regression analyses using all observed values of capacity for a particular machine.

In the 7.2- to 15.3-percent moisture content range for the conventional baler, as the moisture content increased, the packaging capacity increased. When the moisture level increased, the machine speed decreased (Table 2); however, the increase in moisture level increased the bale density (Table 1) and thus the capacity of production (Figure 7), despite the speed decrease.

For the roll baler, a significant linear response was found for capacity versus moisture content. The polynomial regression results indicated a straight line relationship, shown in Figure 7. This

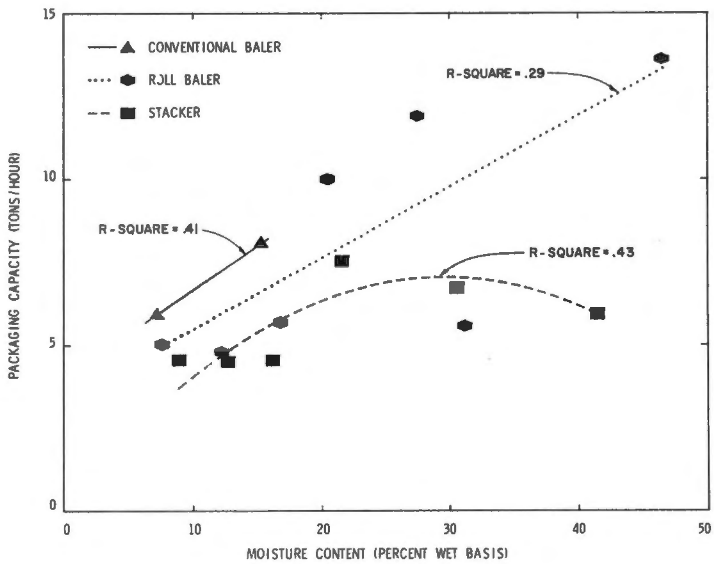

Figure 7. Means of packaging capacity values in terms of total matter as affected by moisture content of the hay.

Table 2. Packaging Moisture Content Effects on Average Speeds for Packaging and Handling Systems

	MOISTURE CONTENT	PACKAGING	HANDLING[1] TO FIELD	HANDLING[1] FROM FIELD TO BARN
	%	MPH	MPH	MPH
Conventional baler	7.2	4.0	10.1	7.4
	15.3	2.8	7.6	7.2
	15.7	2.8	11.5	9.4
Roll baler	7.6	3.7	9.5	7.8
	12.2	2.9		
	16.8	2.7	12.0	10.4
	20.5	3.8	13.3	11.4
	27.5	3.5	9.9	7.7
	31.2	2.9	9.9	8.2
	46.5	1.3	13.5	11.2
Stacker	8.9	2.0	9.7	7.1
	12.7	2.7		
	16.2	2.2	12.6	9.2
	21.6	3.8	13.9	11.1
	30.6	3.2	8.2	5.9
	41.5	.9	13.6	8.0

[1]Average handling distance was 0.6 mile to and from the field.

relationship was weak since the correlation index, or R-square value, for the curve was only 0.29. This value indicates that 29 percent of the variation about the mean was explained by the linear regression. With only slight reduction in forward travel speed, there was a general increase in densities for the cylindrical shaped roll bales with increase in moisture content of the hay. Therefore, the capacity in tons of hay (dry matter plus moisture) per hour processed increased linearly with moisture content (Figure 8).

The packaging capacity for the stacker was most affected by high moisture content hay. A quadratic response for capacity versus hay moisture content was indicated. The quadratic polynomial regression accounted for 43 percent of the variation of capacity values about the overall mean value. The predicted quadratic response is shown by the curve in Figure 7. The capacity curve began to develop a negative slope at percent moisture value of 30.6. As indicated in Table 2, the packaging speed was decreased at this point. At higher moisture contents, overloading the pickup discharge chute of the stacker would cause clogging; therefore the forward travel speed had to be reduced. Like the other two systems, the stack density increased with moisture content (Table 1).

For the 7.2 to 8.9 percent moisture level, where all three machines were compared, no statistical difference in mean capacities of the three machines was found at the 5 percent level of significance (Table 3). At this level the conventional baler tended to have the highest capacity; the roll baler capacity was next; and the stacker tended to have the lowest capacity. For the 15.3 to 16.8 percent moisture level, the difference between the conventional baler and the stacker capacities was

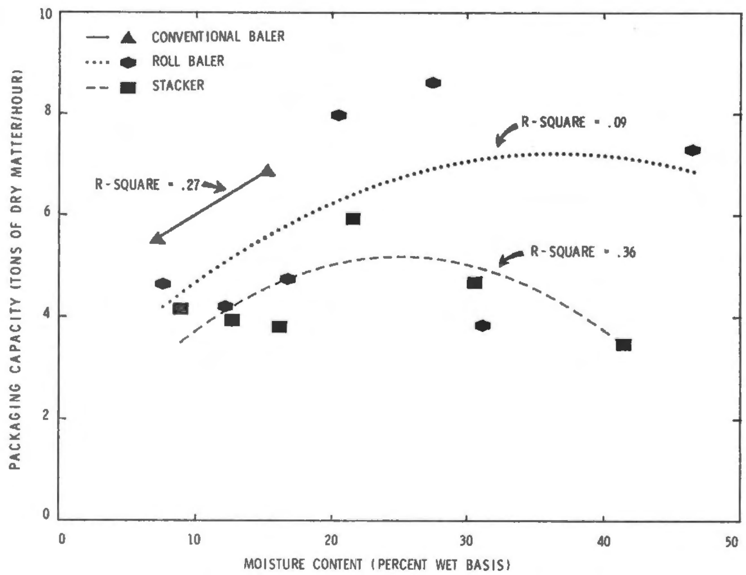

Figure 8. Means of packaging capacity values in terms of dry matter as affected by moisture content of the hay.

Table 3. A Two-Tailed T-Test Comparing the Sample Means at Various Moisture Content Levels (Wet Basis) for Three Packaging and Handling Systems

CLASSIFICATION PAIRS COMPARED		PACKAGING t	PACKAGING df	HANDLING t	HANDLING df
Conventional	Roll Bale[1]	.549	6	.641	6
Roll Bale	Stack	.347	7	- 1.317	7
Stack	Conventional	-1.771	3	.493	3
Conventional	Roll Bale[2]	1.508	15	- 2.085*	15
Roll Bale	Stack	1.076	18	- 9.926*	18
Stack	Conventional	-3.599*	7	9.484*	7
Roll Bale	Stack[3]	1.972*	19	- 5.205*	19
Roll Bale	Stack[4]	2.234*	13	- 4.599*	13
Roll Bale	Stack[5]	4.194*	12	-14.375*	10

*Reject the null hypothesis of no difference between mean capacities at $\alpha = 0.05$.

[1]Conventional (7.2 percent), roll bale (7.6 percent), and stack (8.9 percent) systems compared at observed moisture content (W.B.).

[2]Conventional (15.3 percent), roll bale (16.8 percent), and stack (16.2 percent) systems compared at observed moisture content (W.B.).

[3]Roll bale (20.5 percent) and stack (21.6 percent) systems compared at observed moisture content (W.B.).

[4]Roll bale (27.5 percent) and stack (30.6 percent) systems compared at observed moisture content (W.B.).

[5]Roll bale (46.5 percent) and stack (41.5 percent) systems compared at observed moisture content (W.B.).

significant. The conventional baler had the greater capacity. As can be observed in Table 2, the forward travel speed for the stacker was considerably lower than that of the conventional baler at this moisture level. It is doubtful that the operator was utilizing the full capacity of the stacker. The comparison of packaging capacities for the roll baler and stacker at moisture levels exceeding 20.5 percent indicated a significant advantage for the roll baler.

The tractors which were available for operating the machines were of higher horsepower than the recommended horsepower requirements stated in the operators' manuals. Over-powering the machines would likely increase the operating capacities. For example the percentage of compression time per ton for the stacker (Table 4), might be greatly increased by a tractor smaller than the ones used in the tests.

The packaging in terms of tons of dry matter per hour was similar to the total matter (dry matter plus water) capacity, but somewhat less, as would be expected. Moisture effects were not as great as anticipated, as indicated in Figure 8. The percentage of variation explained by regression generally decreased, as evidenced by lower R-square values. The conventional baler dry matter packaging capacity increased slightly with increased moisture content. The roll baler dry matter packaging capacity increased slowly up to the 25- to 30-percent moisture range. Above this range, the capacity decreased with increasing moisture content. The stacker dry matter packaging capacity followed the same trend as the total matter capacity response. The dry matter packaging capacity (Figure 8), when compared with the total matter capacity (Figure 7), illustrates the loss of total matter when the hay moisture evaporates.

Table 4. Time-Function Analyses for Three Packaging and Handling Systems Based on Time Per Ton

	CONVENTIONAL[1]		ROLL BALE[2]		STACK[3]	
	MINUTES ELAPSED	% OF TOTAL TIME	MINUTES ELAPSED	% OF TOTAL TIME	MINUTES ELAPSED	% OF TOTAL TIME
			Packaging System			
Baling	4.93	66.9	7.25	68.8	9.22	69.8
Compression					1.77	13.3
Turning	.65	8.9	1.60	15.1	1.20	9.1
Down-Time	.38	5.1	.77	7.4		
Changing Wagons	1.42	19.1				
Unload Preparation					.32	2.4
Unloading			.92	8.7	.72	5.4
Total Time	7.38		10.54		13.23	
			Handling[4] System			
Loading			2.28	9.0	.82	8.9
Travel to Field	3.07	9.1	9.95	39.6	3.18	35.1
Backing	.78	2.3				
Hook Up to Wagon	25.33	75.3	1.17	4.6	.67	7.3
Travel to Storage Area	3.35	10.0	11.78	46.8	4.45	48.7
Unhook Wagon	.27	.8				
Total Time	33.65		25.18		9.12	

[1]Hay loads averaging 1.700 tons per wagon at 15.3 percent moisture content (W.B.).

[2]Roll bales averaging 0.303 ton per bale at 16.8 percent moisture content (W.B.).

[3]Stacks averaging 0.882 ton per stack at 16.2 percent moisture content (W.B.).

[4]Average handling distance was 0.6 mile to and from the field.

The average mean field efficiencies for packaging are presented in Table 5. The roll baler spent more time in the actual baling process than the stacker and conventional baler. Typical time-function analyses for the three systems at the 15.3 to 16.8 percent moisture level can be observed in Table 4. The compression phase, and backing in the unloading preparation phase, were time-consuming for the stacker. Although down-time for the roll baler also was time-consuming, less total time per ton of hay was needed for the roll baler than for the stacker. The time needed for hooking and unhooking the hay wagon used time for the conventional system. The turning time percentage for the roll baler was much greater than for the other two systems, in which the turning time percentages were essentially equal.

The highest material efficiency of the three systems for packaging and handling was that of the conventional system (Table 5). The roll baler and stacker had some losses along the windrow while packaging, and losses from picking up and transporting the hay units (remnant losses). These lowered the yield efficiency. The largest remnant losses were measured for the roll bale system when the hay was dry (7.6 to 16.8 percent moisture). Parts of the roll would slough off when the package was discharged from the baler and when lifted for transport. It can be said for all three systems that the better the formation of the package, the higher will be the efficiency of the material.

III. HANDLING FIELD CAPACITIES

A linear response was indicated for all three handling systems by regression analyses for handling capacity versus hay moisture content.

Table 5. Average Mean Field and Material Efficiencies for Three Hay Packaging Systems

HAY PACKAGING SYSTEM	FIELD EFFICIENCY[1]		PACKAGING MATERIAL EFFICIENCY[2]
	PACKAGING	HANDLING	
	%	%	%
Conventional	65.6	25.9	98.3
Roll Bale	75.9	89.0	94.3
Stack	69.8	83.2	96.9

[1]Field efficiency is the ratio of effective field capacity to theoretical field capacity, Bowers (4). Effective field capacity is the actual rate of performance based on total field time. Theoretical field capacity is the rate of performance obtained if a machine performs its function 100 percent of the time at the rated operating speed and maximum rated width.

[2]Hunt (29) defines material efficiency as the percentage of crop yield which is conserved by the handling processes involved in harvesting. Only packaging material efficiency, that percentage of hay available in the windrow that was packaged and delivered to the storage area by the machine system used, was evaluated in this study.

The handling capacity for the stack and roll bale system increased with an increase in moisture content. For the conventional handling system, the capacity decreased. This effect of moisture content of the hay on the three handling systems is shown in Figure 9.

At the 7.2 to 8.9 percent moisture content level, no statistical difference was found between the three handling systems (Table 3, page 34). The stack handling system tended to have the highest capacity, the conventional system was next, and the roll bale system tended to have the least handling capacity at this moisture content. A significant difference was found among all three systems at the 15.3- to 16.8-percent moisture level. At this moisture content the stack system handling capacity was highest, and the roll bale system handling capacity was greater than that of the conventional baler system. At moisture levels of 15.3 percent and higher, the stack system handling capacity was significantly greater than that of the roll bale system.

Unloading the bales from the wagon by hand resulted in the low handling capacities with the conventional system. The higher moisture content bales were heavier and thus increased unloading time. Table 2, page 31, indicates that transport of the wagon loaded with conventional bales was about two miles per hour slower than the transport speed for the other two systems. An analysis of time-function relationships in handling and transporting the hay units is given in Table 4, page 36. The one-man unloading of conventional bales without an elevator resulted in excessive time consumption. Hooking and unhooking the wagon, along with backing, used valuable time. The average handling field efficiency for the conventional system was calculated to be the lowest of the three systems (Table 5).

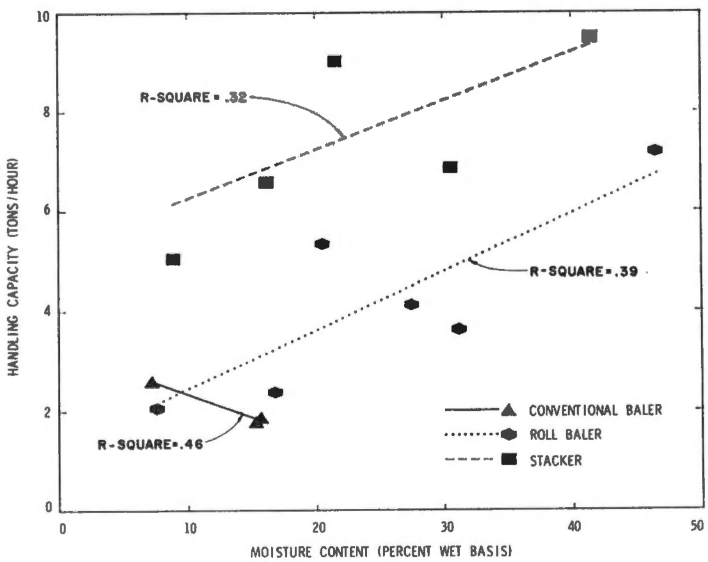

Figure 9. Means of handling capacity values in terms of total matter as affected by moisture content of the hay.

The same transporting equipment was used for rolls and stacks. Since the stacks weighed approximately twice that of the roll bales, the capacity for the stack handling system was about twice the roll bale handling capacity. Time-function data (Table 4) indicates the roll bale handling time per ton to be more than twice that for stacks with moisture in the 16.2 to 16.8 percent range. Transport speeds on the road were essentially equal for handling rolls and stacks of hay (Table 2, page 31). Average field efficiencies for the handling operation indicated that the roll bale system was more efficient than the stack system (Table 5). The difference in capacity was related to the weight of package handled.

When handling capacity was considered on a dry matter basis, the correlation with moisture content decreased for the stack and roll bale systems (Figure 10). The stack handling capacity decreased with increasing moisture content above a moisture level of 30.6 percent. Table 2 lists the decrease in traveling speed for the tractor when moving high moisture stacks. The higher moisture stacks were sufficiently heavy to affect the stability of the tractor and thus required a reduction in travel speed from the field to the stackyard. As a result, the stack handling capacity was reduced. The regression curves for the conventional and roll bale handling capacities in tons of dry matter per hour were similar to curves for these hay units on a total matter basis.

The compressed stacks and roll bales could be left in the field where discharged and moved at a later time. The wagon-load lots of conventional bales had to be transported to the storage area immediately

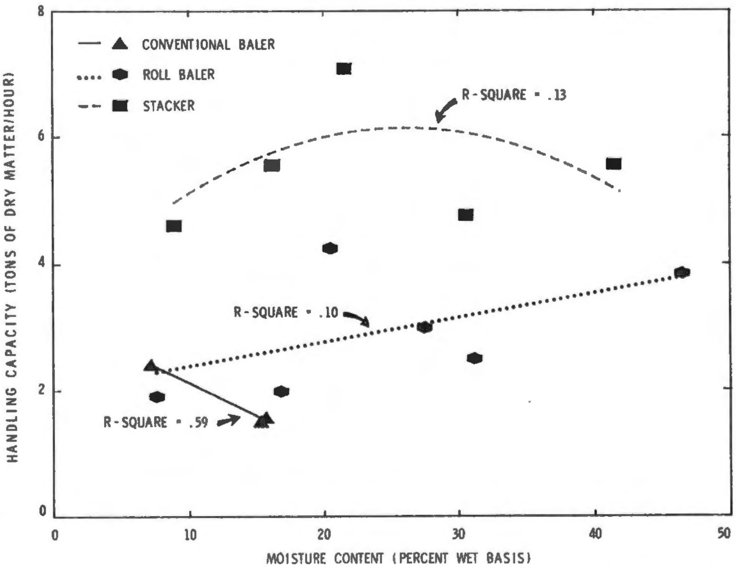

Figure 10. Means of handling capacity values in terms of dry matter as affected by moisture content of the hay.

after baling if the number of wagons were kept to a minimum. This difference gave the large hay units an advantage where likelihood of weather damage was a problem such that it was important to package the hay as quickly as possible.

IV. ECONOMIC COMPARISONS OF THE THREE SYSTEMS

The cost analyses are based on a yearly production of 500 tons of Midland bermudagrass hay. Observed average packaging and handling capacities for the three systems were used to determine the expected average yearly use of each machine at a given moisture level. These data were used to determine the cost per ton of hay. The cost calculations included the tractor cost, machine cost, labor cost, and cost of required extra tractor options.

The economic analyses for the conventional packaging and handling systems are shown in Table 6. The added cost for twine and a four wheeled wagon was required for this system. The cost of owning a hay elevator was not included in the cost calculations since unloading of the conventional bales was done by hand in this study. The cost information presented in Table 6 is applicable only to bermudagrass hay of 15.3 percent moisture content.

Since all three systems were "over-powered" by the 60 to 95 horsepower tractors used, the packaging and handling capacities were greater than would be expected with smaller tractors. In the cost calculations, a 60-horsepower tractor was selected as the average minimum available horsepower tractor suitable for use with any of the three systems. The roll bale packaging and handling system (Table 7)

Table 6. Economic Analyses of Conventional Bale Packaging and Handling System

	PACKAGING			HANDLING	
	TRACTOR[1]	CONVENTIONAL BALER[2]	HAY WAGON[3]	TRACTOR[1]	HAY WAGON[4]
<u>FIXED COST</u>[5]					
Depreciation[6]	.81	4.90	.49	.81	.11
Interest[7]	.41	2.10	.25	.41	.06
Housing Cost[8]	.01	.28	.26	.01	.06
Insurance[9]	.04	.18	.02	.04	.01
TOTAL FIXED COST	1.27	7.46	1.02	1.27	.24
<u>VARIABLE COST</u>					
Fuel[10]	.58			.58	
Lubrication[11]	.09	.11	.01	.09	.003*
Repair and Maintenance[12]	.78	1.00	.07	.78	.07
Twine[13]		3.58			
Labor[14]	2.00			2.00	
TOTAL VARIABLE COST	3.45	4.69	.08	3.45	.07
<u>TOTAL COST</u>	4.72	12.15	1.10	4.72	.31
SYSTEM TOTAL COST/HOUR		$17.97/hour		$5.03/hour	

[1]Tractor rated at 60 horsepower and used 600 hours per year for 12 years.

[2]New Holland model 273 baler with model 54 PTO driven bale thrower used 61.5 hours per year for 10 years on 500 harvested tons per year (three hay cuttings of 75 acres yielding 2.22 tons per acre); average machine packaging capacity equals 8.123 tons per hour and based on hay moisture content of 15.3 percent (wet basis).

[3]Wagon with three ton capacity and 8' x 16' wagon bed used 61.5 hours per year for 12 years.

[4]Wagon with three ton capacity and 8' x 16' wagon bed used 280.4 hours per year for 12 years on 500 harvested tons per year; average machine handling capacity equals 1.783 tons per hour and based on hay moisture content of 15.3 percent (wet basis) over an average handling distance of six-tenths of a mile.

[5]Glover, calculated by outlined procedure in text.

[6]Straight line depreciation; Ray and Walch, useful machine life.

[7]Seven percent on the average investment.

[8]Ten cents per square foot of floor space.

[9]Ninety cents per $100 for two-thirds of the machine value.

[10]Nebraska Tractor Test Data for 1972, average of 3.65 gallons per hour.

[11]Bowers, 15 percent of fuel cost for tractor; Larson <u>et al</u>., 0.2 percent of purchase price for baler and wagon.

[12]Hunt, percentage of purchase price for tractor (0.012), baler (0.031), and wagon (0.018).

[13]Hunt, three pounds of twine per ton of hay.

[14]Farm Labor, average hourly farm wage rate in the United States.

* Eighty-one cents per year.

Table 7. Economic Analyses of Roll Bale Packaging and Handling System

	PACKAGING		HANDLING	
	TRACTOR[1]	ROLL BALER[2]	TRACTOR[1]	STACKMOVER[3]
FIXED COST[4]				
Depreciation[5]	.81	4.06	.81	.24
Interest[6]	.41	1.73	.41	.01
Housing Cost[7]	.01	.24	.01	.03
Insurance[8]	.04	.15	.04	.01
TOTAL FIXED COST	1.27	6.18	1.27	.29
VARIABLE COST				
Fuel[9]	.58		.58	
Lubrication[10]	.09	.09	.09	
Repair and Maintenance[11]	.78	1.23	.78	.10
Labor[12]	2.00		2.00	
TOTAL VARIABLE COST	3.45	1.32	3.45	.10
TOTAL COST	4.72	7.50	4.72	.39
SYSTEM TOTAL COST/HOUR	$12.22/hour		$5.11/hour	

[1]Tractor rated at 60 horsepower and used 600 hours per year for 12 years.

[2]Hawk Bilt Model 480 roll baler used 87.8 hours per year for 10 years on 500 harvested tons per year (three hay cuttings of 75 acres yielding 2.22 tons per acre); average machine packaging capacity equals 5.692 tons per hour and based on hay moisture content of 16.8 percent (wet basis).

[3]Hesston Stakmover number 10 used 209.8 hours per year for 10 years on 500 harvested tons per year; average machine handling capacity equals 2.383 tons per hour and based on hay moisture content of 16.8 percent (wet basis) over an average handling distance of six-tenths of a mile.

[4]Glover, calculated by outlined procedure in text.

[5]Straight line depreciation; Ray and Walch, useful machine life.

[6]Seven percent on the average investment.

[7]Ten cents per square foot of floor space.

[8]Ninety cents per $100 for two-thirds of the machine value.

[9]Nebraska Tractor Test Data for 1972, average of 3.65 gallons per hour.

[10]Bowers, 15 percent of fuel cost for tractor; Larson et al., 0.2 percent of purchase price for baler and stackmover.

[11]Hunt, percentage of purchase price for tractor (0.012), baler (0.031), and stackmover (0.018).

[12]Farm Labor, average hourly farm wage rate in the United States.

required no extra equipment other than a 60-horsepower tractor. When using this same horsepower tractor with the stack system, a dual hydraulic system was needed for operating the stacker, and extra front end weights were essential for handling the one ton stacks with a 3-point hitch stack-mover attachment. The effect these extras have on total cost can be seen in Table 8. Capacities for the 16.8 to 16.2 percent moisture range for the roll bale and stack system were used in calculating the cost figures reported in Tables 7 and 8. When capacity was lower, the machine was used more hours per season, which would decrease the hourly cost but would unfavorably affect the total cost per ton.

A comparison of the three systems on the basis of total cost per ton for packaging and handling at the 15.3 to 16.8 percent moisture content level is shown in Table 9. The stack total cost per ton was 67 cents less than the roll bale system because of the much higher handling capacity of the stack system. The difference in capacity for the roll bale and the stack packaging systems was not statistically significant at the 5 percent level (Table 3, page 34). The stack system cost was $1.41 less than the conventional system, and the roll bale system was 75 cents cheaper than the conventional system. The lower handling capacity caused the total cost per ton for the conventional system to be higher than the other two systems. The extra labor (man-hours) needed for unloading the conventional bales by hand increased the total cost. The total cost per ton dry weight was consistently higher than per ton total weight cost for all three systems. Capacity

Table 8. Economic Analyses of Stack Packaging and Handling System

	PACKAGING		HANDLING	
	TRACTOR[1]	STACKER[2]	TRACTOR[3]	STACKMOVER[4]
FIXED COST[5]				
Depreciation[6]	.83	4.08	.84	.65
Interest[7]	.43	1.75	.43	.03
Housing Cost[8]	.01	.15	.01	.07
Insurance[9]	.04	.15	.04	.02
TOTAL FIXED COST	1.31	6.13	1.32	.77
VARIABLE COST				
Fuel[10]	.58		.58	
Lubrication[11]	.09	.09	.09	
Repair and Maintenance[12]	.80	1.55	.80	.10
Labor[13]	2.00		2.00	
TOTAL VARIABLE COST	3.47	1.64	3.47	.10
TOTAL COST	4.78	7.77	4.79	.87
SYSTEM TOTAL COST/HOUR		$12.55/hour		$5.66/hour

[1]Tractor rated at 60 horsepower, includes dual hydraulic system, and used 600 hours per year for 12 years.

[2]Hesston Stakhand number 10 used 110.1 hours per year for 10 years on 500 harvested tons per year (three hay cuttings of 75 acres yielding 2.22 tons per acre); average machine packaging capacity equals 4.539 tons per hour and based on hay moisture content of 16.2 percent (wet basis).

[3]Tractor rated at 60 horsepower, includes front end weights totaling 682.22 pounds, and used 600 hours per year for 12 years.

[4]Hesston Stakmover number 10 used 76.0 hours per year for ten years on 500 harvested tons per year; average machine handling capacity equals 6.581 tons per hour and based on hay moisture content of 16.2 percent (wet basis) over an average handling distance of six-tenths of a mile.

[5]Glover, calculated by outlined procedure in text.

[6]Straight line depreciation; Ray and Walch, useful machine life.

[7]Seven percent on the average investment.

[8]Ten cents per square foot of floor space.

[9]Ninety cents per $100 for two-thirds of the machine value.

[10]Nebraska Tractor Test Data for 1972, average of 3.65 gallons per hour.

[11]Bowers, 15 percent of fuel cost for tractor; Larson et al., 0.2 percent of purchase price for stacker and stackmover.

[12]Hunt, percentage of purchase price for tractor (0.012), stacker (0.031), and stackmover (0.018).

[13]Farm Labor, average hourly farm wage rate in the United States.

Table 9. Effect of Three Systems of Hay Packaging on Cost per Ton of Hay

ITEM	CONVENTIONAL[1] SYSTEM		ROLL BALE[2] SYSTEM		STACK[3] SYSTEM	
	Per Ton Total Weight	Per Ton Dry Weight	Per Ton Total Weight	Per Ton Dry Weight	Per Ton Total Weight	Per Ton Dry Weight
Packaging Cost	$2.21	$2.61	$2.15	$2.58	$2.76	$3.30
Handling Cost	$2.82	$3.33	$2.14	$2.58	$ .86	$1.03
Total Cost	$5.03	$5.94	$4.29	$5.16	$3.62	$4.33

[1]Based on 15.3 percent moisture content (W.B.), $17.97 per hour packaging and $5.03 per hour handling at observed mean capacities.

[2]Based on 16.8 percent moisture content (W.B.), $12.22 per hour packaging, and $5.11 per hour handling at observed mean capacities.

[3]Based on 16.2 percent moisture content (W.B.), $12.55 per hour packaging, and $5.66 per hour handling at observed mean capacities.

had a greater effect on hay unit production cost than did original equipment cost or operating cost.

The roll bale and stack systems are compared in Table 10 at the 20.5 to 21.6 percent moisture levels. The roll bale system cost 17 cents per ton less than the stack system. This difference is explained by the fact that the roll bale packaging capacity had a greater effect on the total cost than the stack handling capacity did. Capacity, not initial equipment cost, was the key. Total costs based on hay dry weight were less for the roll baler, also.

At the 27.5 to 30.6 percent level, the roll bale system cost was 25 cents per ton less than the stack total system cost. The stack packaging capacity was affected negatively at this moisture level (Figure 7, page 30). The trend was for the roll bale system to be cheaper than the stack system cost per ton of hay as moisture increased (Table 11).

V. HAY QUALITY AFTER THE CURING PROCESS

Core samples were taken from each experimental unit of hay for quality evaluations. Ratings for the units according to visual inspection of the core samples are given in Table 12. The peak internal temperature attained during the curing period is listed for those hay units in which it was measured.

The peak bale internal temperature was greater for conventional bales of higher density. When densities were about the same, quality of hay decreased with greater initial moisture content (Table 12). For

Table 10. Effect of Two Systems of Higher Moisture Hay Packaging on Cost per Ton of Hay

ITEM	ROLL BALE[1] SYSTEM		STACK[2] SYSTEM	
	Per Ton Total Weight	Per Ton Dry Weight	Per Ton Total Weight	Per Ton Dry Weight
Packaging Cost	$1.68	$2.11	$2.21	$2.81
Handling Cost	$1.02	$1.28	$ .66	$ .84
Total Cost	$2.70	$3.39	$2.87	$3.65

[1]Based on 20.5 percent moisture content (W.B.), $16.79 per hour packaging, and $5.45 per hour handling at observed mean capacities.

[2]Based on 21.6 percent moisture content (W.B.), $16.55 per hour packaging, and $5.95 per hour handling at observed mean capacities.

Table 11. Effect of Two Systems of High-Moisture Hay Packaging on Cost per Ton of Hay

ITEM	ROLL BALE[1] SYSTEM		STACK[2] SYSTEM	
	Per Ton Total Weight	Per Ton Dry Weight	Per Ton Total Weight	Per Ton Dry Weight
Packaging Cost	$1.60	$2.21	$2.31	$3.32
Handling Cost	$1.29	$1.78	$ .83	$1.20
Total Cost	$2.89	$3.99	$3.14	$4.52

[1]Based on 27.5 percent moisture content (W.B.), $19.05 per hour packaging, and $5.31 per hour handling at observed mean capacities.

[2]Based on 30.6 percent moisture content (W.B.), $15.54 per hour packaging, and $5.70 per hour handling at observed mean capacities.

Table 12. Hay Quality as Affected by Inside and Outside Storage Conditions for Three Systems at Various Moisture Levels

			STORAGE							
			INSIDE				OUTSIDE			
SYSTEM	MOISTURE CONTENT	AVERAGE HAY DENSITY	QUALITY[1]	COLOR[2]	ODOR[3]	TEMPER-ATURE[4]	QUALITY[1]	COLOR[2]	ODOR[3]	TEMPER-ATURE[4]
	%	lb/ft³				°F				°F
Conventional bale	7.2	9.6	H	1.3	1.7	83				
	15.3	11.2	H	2	2.7	98				
	15.7	6.4	M-H	2.7	2	85				
Roll bale	7.6	4.8	H	2	1.5		H	2	2.3	
	12.2	5.3					L[5]	3.3	3.4	
	16.8	5.2	M-H	2.8	2.3	84	M	3	3.1	98
	20.5	6.6	M-H	2.6	2.9		M-H	2.6	3.4	
	27.5	7.8	M-H	2.5	2.3	119	M	2.7	3	128
	31.2	12.1	L	3.5	3.3	144	L	3	3.3	139
	46.5	11.7	L	4	4	150	L	4	4	144
Stack	8.9	4.1	H	1	1		H	1.8	3.2	
	12.7	5.2	H	4	2	97	M	3	2	99
	16.2	4.4	M	3	3	89	M	3	2.7	97
	21.6	4.9	H	2	1		M	2.1	3	
	30.6	6.0	M	2.5	2	126	M	2.6	3	128
	41.5	6.5	L	3.5	3.5	143	L	2.8	3.3	152

Table 12 (continued)

[1] High quality hay (H), medium quality hay (M), and low quality hay (L).

[2] Light green (1), olive green (2), yellow to slight brownish (3), and brown to black (4).

[3] Light and pleasant (1), dusty (2), slightly musty (3), and musty (4).

[4] Maximum hay temperature during curing (°F).

[5] Roll bales were transported 3.0 miles the day after baling; rough roads severely shook the packages of hay and may have decreased bale density.

conventional bales stored inside, greater density increased the temperature during curing even for the same moisture content. Rate of weight loss and total weight loss were greater for the 15 to 16 percent moisture hay than for the 7.2 percent moisture hay (Figure 11).

Medium-to-high quality hay was maintained for roll bales stored inside up to about 27.5 percent moisture content. Densities and peak temperatures were relatively low for rolls up to this moisture level. Above 31.2 percent moisture content, the temperature rose above 140° F, and the quality of hay was low.

Roll bales stored outside were of high quality at the 7.6 percent moisture level, of medium quality at the 16.8 to 27.5 percent moisture level, and of low quality above 31.2 percent moisture. In the 16.8 to 27.5 percent moisture range, outside storage appeared to lower the quality from high to medium. Peak temperatures were lower for the high moisture roll bales stored outside (Table 12). Quality decreased with increase of density and initial moisture content of the hay. As the hay in the roll bales cured, the rate of total weight loss was greatest during the interval from 20 to 45 days after packaging (Figure 12). The rate of total weight reduction was less for lower moisture hay.

Hay quality for the stacks stored inside was high for the initial moisture contents of 8.9 to 21.6 percent, of medium quality for 30.6 percent initial moisture content, and of low quality for 41.5 percent initial moisture content hay. The highest internal peak temperature for stacks stored inside was 143° F (Table 12). Hay in this stack was judged

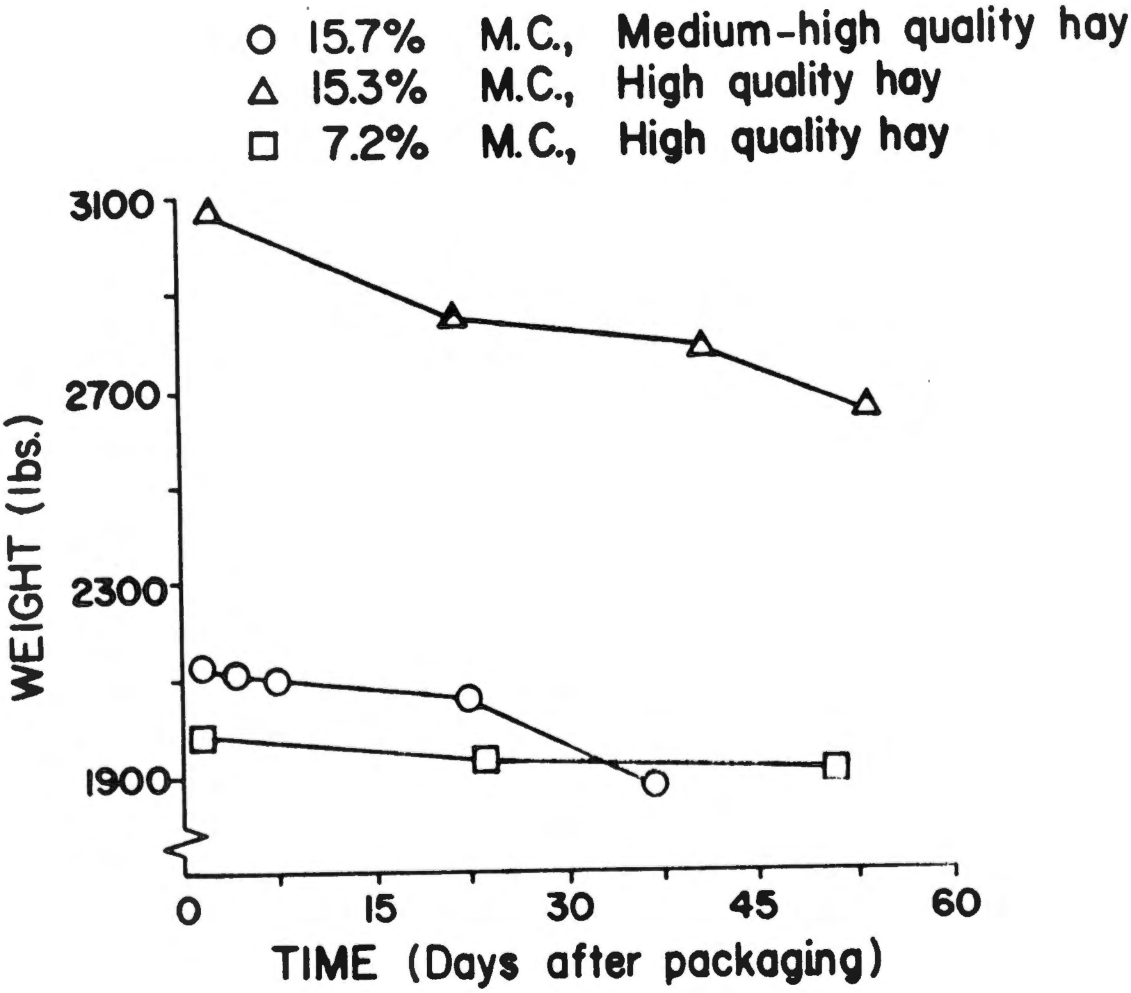

Figure 11. Conventional bale total weight change with time subsequent to packaging.

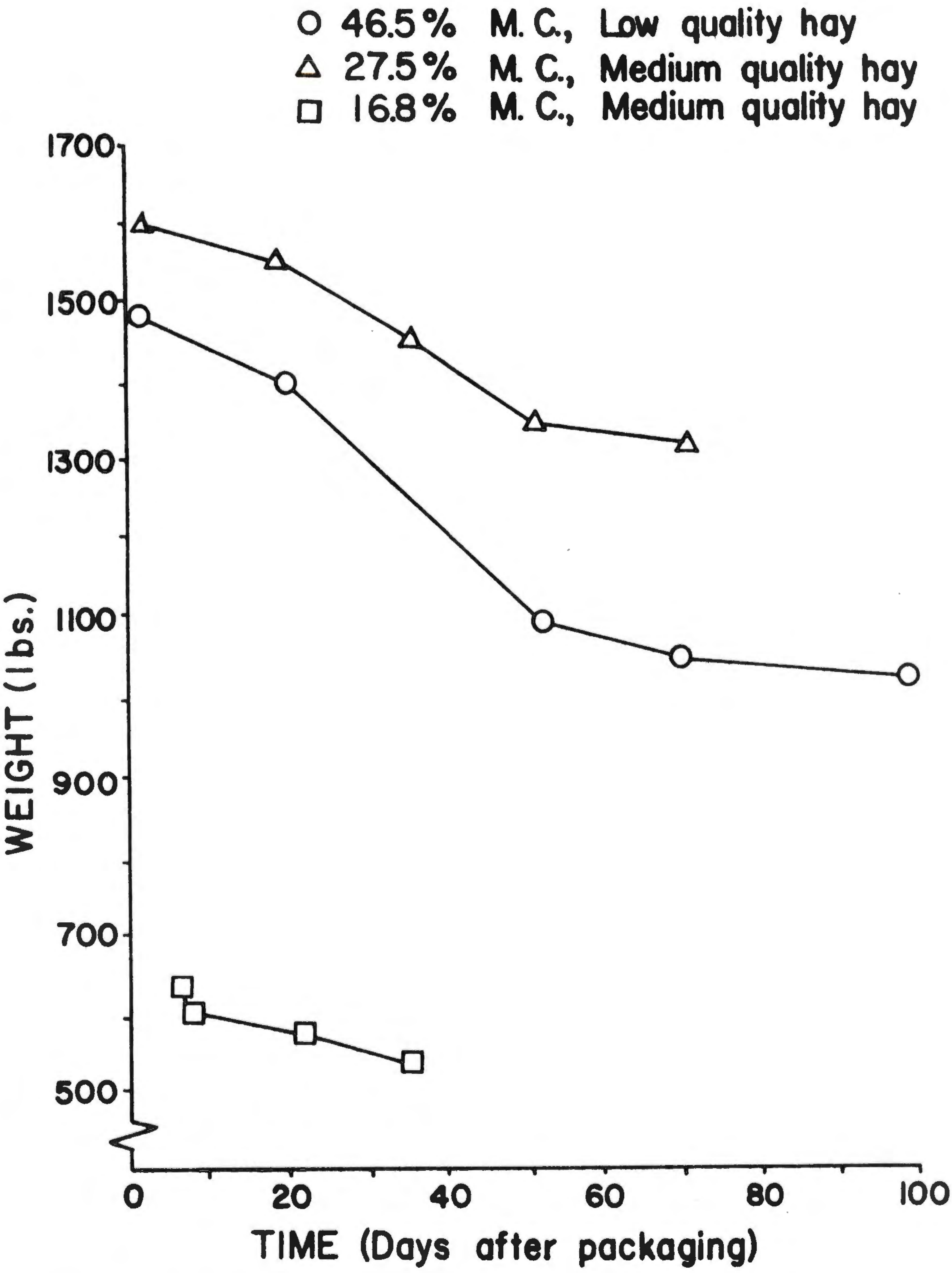

Figure 12. Roll bale total weight change with time subsequent to packaging.

to be of low quality. As with the roll bales, increased moisture content brought increased density and lower hay quality.

Stacks stored outside were of high quality up to 8.9 percent moisture content, of medium quality with initial moisture contents of 41.5 percent. The stacks were lower in density than the rolls and apparently more permeable to rain water. In contrast to the results obtained with roll bales, the stacks stored outside had higher peak internal temperature during curing than the stacks of the same initial moisture content hay stored inside. The pattern of weight loss with time for stacks was similar to that for roll bales (Figure 13).

At the 15.7 percent moisture content and lower, conventional bales were demonstrated to be superior in color and odor to roll bales and stacks stored indoors. The hay color and odor ratings for roll bales and stacks stored outdoors usually were a little less desirable than identical moisture content hay stored indoors. Stacks maintained a more desirable color and odor rating at the low and extremely high moisture levels in comparison to the roll bales at the same levels. Outside storage affected the quality of the hay in the stacks to a lesser degree than the hay in the roll bales.

The loss of hay quality and reduction in green color and pleasant odor for higher moisture content hay can be attributed to higher bale densities. This effect is indicated in Table 12 by higher maximum hay temperature reached during the curing period for the denser packages. When maximum hay temperatures exceeded about 140° F, results indicated low quality hay.

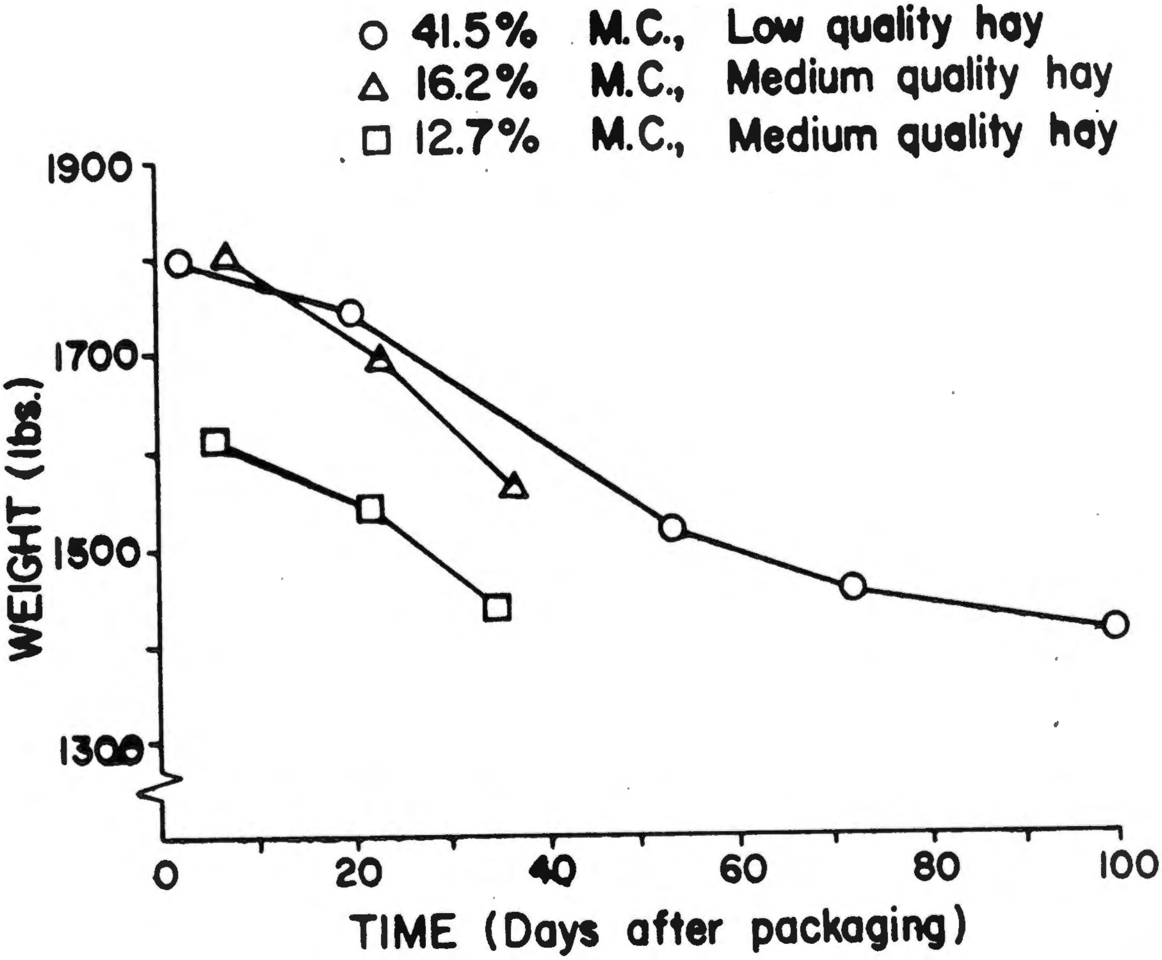

Figure 13. Stack total weight change with time subsequent to packaging.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

In this study, comparisons were made of a conventional bale, a roll bale, and a stack system for packaging and handling Midland bermudagrass hay. Packaging and handling capacity, field efficiency, material efficiency, cost per ton of hay, and hay quality were determined for each system. Field operations of the three packaging and handling systems were conducted on Midland bermudagrass hay ranging in moisture content from 7.2 to 46.5. All three systems were operated and compared in hay ranging from 7.2 to 16.8 percent moisture content. At the 20.5 percent moisture content and above, only the roll bale and stack systems were compared.

The conventional bale packaging system produced the most stable packages (30 inch long, dense bales) which were best suited for handling when the hay was extremely dry (7.2 percent moisture). All systems produced stable packages with hay of 15.3 percent or greater moisture. The roll baler was more efficient in dealing with higher moisture content hay than the stacker. This difference resulted in higher packaging capacities for the roll baler in hay above 16.8 percent moisture. Bale weight was the most significant variable controlling the response in the handling phase. Since a stack weighed approximately twice the weight of a roll bale, the stack handling capacity consistently doubled the roll bale capacity. Cost calculations were greatly influenced by the packaging and handling capacity of the complete system at a specified moisture content range. At the low moisture content range, the stack was the cheapest system to operate because of the excellent handling capacity. As the moisture content increased above 20.5 percent, the roll bale system was the cheaper per ton of hay. This was due to the advantage accrued from the packaging capacity of the roll baler.

The conventional method of baling and transporting hay was more time consuming than the new roll bale or stack methods. Although the roll bale and stack systems were capable of baling hay at higher moisture levels than the conventional system, there was an increased chance of excessive waste subsequent to storage. Inside storage for roll bales and stacks conserved the quality of hay better than outside storage.

The initial investment cost for each system was not significantly different and was not a limiting factor in cost considerations. The major effect on cost was packaging or handling capacity. Increasing the moisture content of the hay could have either positive or negative effects on the capacities of the systems. As a rule, the system which maintained the superior capacity during either the packaging or handling process consistently was the cheapest to operate per ton of hay.

II. CONCLUSIONS

The following conclusions were drawn from the results:

1. Attempts to package short-leafed Midland bermudagrass hay at low moisture contents of 7.2 to 8.9 percent caused difficulties for each of the packaging machine systems. The most stable

package for this type material proved to be short (30-inch) conventional bales packed to a high density (9.6 to 11.2 pounds per cubic foot). With hay leaves 15 inches or longer at moisture contents 15.3 percent and higher, stable packages were readily formed with each packaging machine.

2. Packaging material efficiency was greatest for the conventional baler (98.3 percent), followed by that of the stacker (96.9 percent), and of the roll baler (94.3 percent).
3. The stacker was the most flexible and maneuverable packaging machine. The roll baler was the least maneuverable because of its greater required turning radius.
4. Packaging and handling field efficiencies were greatest for the roll bale system, followed by those of the stacker and of the conventional system, respectively.
5. For operator comfort and convenience, the three packaging machines were rated in the following order: roll baler, conventional baler, and stacker. The dust and chaff created by the air blast from the discharge chute of the stacker pickup blower caused minor operator discomfort.
6. At $P \geq 0.05$, no significant differences in packaging capacity (total matter) was found for the three machines with low moisture hay (7.2 to 15.3 percent). However, the conventional baler tended to have a higher capacity, followed by the roll baler and then the stacker. With hay moisture contents 20.5 percent and greater, the roll baler had a significantly higher packaging capacity than the stacker.

7. The compressed stacks and roll bales could be left in the field where discharged from the packaging machines and moved at a later time. The wagon-load lots of conventional bales had to be transported to the storage area immediately after baling if the number of wagons were kept to a minimum. This difference gave the large hay units an advantage where likelihood of weather damage was a problem. If it is important to remove the hay units from the field soon after packaging, then the compressed stack method is the preferred system because of its associated higher handling and transport capacity.
8. With hay moisture content from 7.2 to 8.9 percent, no significant difference was found in handling capacity (total matter) for the three systems. But with hay of 15.3 percent or greater moisture content, there were significant differences among the handling capacities of the systems. The stack system had greatest capacity, the roll baler was intermediate, and the conventional system was least.
9. For hay at 15.3 to 16.8 percent moisture content, combined cost per ton of hay for packaging and handling was lowest for the stack system ($3.63), intermediate for the roll bale system ($4.29), and highest for the conventional system ($5.03). High cost of hand unloading of bales and cost of required baler twine penalized the conventional system. For hay at 20.5 to 21.6 percent moisture content, total cost per ton was slightly

less for the roll bale system ($2.70) than for the compressed stack system ($2.87). For hay at 27.5 to 30.6 percent moisture, total cost per ton was $2.89 for the roll baler and $3.14 for the stacker.

10. Visual ratings of core samples from the hay units indicated that satisfactory hay was packaged in roll bales and stored when initial moisture content was as high as 27.5 percent. Satisfactory stacks were packaged and stored with initial hay moisture contents up to 30.6 percent. Inside storage preserved the quality of the hay as compared to outside storage but did not allow use of higher initial moisture content hay.

11. Poor hay color and odor were prevalent in roll bales exceeding 27.5 percent moisture content and stacks exceeding 30.6 percent moisture content. Since stacks were compressed to a lower density than roll bales or conventional bales, stacks could be stored at a higher moisture level.

III. RECOMMENDATIONS FOR FURTHER STUDY

Since the effect of moisture content of the hay at time of baling was the major effect on machine capacity, I suggest that this effect be controlled much more closely in further studies. Techniques for more adequate control might include such procedures as standardized methods of moisture-level determination for technicians to employ, more adequate instrumentation, and fuller, more accurate records. A closer surveillance of the prospective hay yield would aid in judging drying characteristics and maintaining the specified number of experimental units.

In order to collect all data which would be vital to the experiment, a sufficient number of workers should be available. Also, tractor operators should be checked for their ability to operate the designated machines. This preliminary caution will be time-saving later and will be crucial to the success of the project.

Portable field scales should be located in the field to measure that portion of the packaged bale or stack which might be lost in transporting. Easily accessible hay storage areas or barns would alleviate the excessive time consumption of the transporting phase.

Improved prior planning would serve to eliminate repetitious decisions associated with large experiments of this nature.

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VITA

William Leo Kilgore was born in Argos, Indiana, on April 16, 1949. He is the son of Herschel Leo and Martha Jean Kilgore. He has three sisters: Mary Esther, Wanda Jo, and Darlene Jean. In June of 1967, he graduated from high school in Hazlehurst, Mississippi. With the stipend of an athletic grant-in-aid scholarship to participate on the Mississippi State University track team, he entered the university majoring in Agricultural Engineering Technology and Business. He was actively involved in the AETB Club, Alpha Zeta, M-Club, and Fellowship of Christian Athletes. He received his Bachelor of Science degree in AETB in June, 1971. In September, 1971 he enrolled in the Master's degree program in Agricultural Mechanization at the University of Tennessee where he expects to receive the Master of Science degree in June, 1973. At the University he was a member of the Agricultural Mechanization Club and Gamma Sigma Delta, the honorary society of agriculture.

He is the fiance of Margaret Frances Mercer of Vicksburg, Mississippi, who he will marry on June 30, 1973.