Performance of Large Balers for Collecting Rice Straw

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ABSTRACT

A large rectangular baler was tested and evaluated for application in harvesting rice straw. Baler performance is compared to that of big roll balers and other handling systems. Large bale systems offer economic advantages over small rectangular bale systems. Large rectangular bales are excellent for transport but must be provided with covered storage to avoid spoilage. Big roll bales are less desirable for long distance transport but can be left in uncovered storage without excessive dry matter loss. Total delivered cost of straw depends on packaging system, transporation distance, processing requirements, and utilization mode.

INTRODUCTION

Post harvest open-field burning of rice straw in California is the primary motivation for finding alternative handling methods for the straw. Uses for straw include animal feed, fuel, and fiber for paper or structural board applications. Direct application of hay and forage harvesting equipment to straw collection is hindered by poor soil conditions, short seasons, and the physical properties of the straw. Big roll bale systems have had the most success in handling rice straw. Large rectangular balers offer substantial transporation advantages but until this time had not been tested in rice straw.

About 200,000 ha are planted to rice in California (Knutson and Miller, 1982). Ninety percent is grown in seven contiguous counties within the Sacramento Valley. Straw yield depends on the variety planted. The move to short statured varieties has reduced the yield of straw in the last few years. Straw yield currently averages 6 t/ha on a moisture free basis. Straw moisture content may run as high as 80% wet basis at the time of harvest.

Wet weather during the fall harvest season generally makes field mobility difficult. Rice combines are usually equipped with full- or half-tracks to improve mobility. A full track combine has a vehicle cone index of 240 kPa or less (Kamp et al., 1983). Straw collection equipment must also have low soil strength requirements, particularly because the collection operation occurs at least several days later in the season when the chance of rain is higher.

Several different methods for collecting and handling rice straw have been tried in the past. Dobie et al. (1977) reported on tests with field cubers, stackwagons, buckrakes, standard three wire balers, conventional big roll balers, and high flotation big roll balers. Dobie concluded that a system employing a 1.2 m wide big roll baler would have lowest total delivered cost for a 16 km haul distance. Dobie (1980) also indicated that a large rectangular bale system might have better potential than the big roll bale systems, although he had not tested a large rectangular baler.

OBJECTIVES

The objective of this study was to test and evaluate a large rectangular baler for handling rice straw. This included conducting time and motion studies on the baler and performing an economic analysis of straw collection based on the field data. The system would also be compared to other straw handling systems.

EXPERIMENTAL

Large rectangular baler

A Hesston model 4800 Big Baler with model 4820 bale accumulator was supplied by Hesston Corporation through Gates Machinery Company, Willows, CA. A Case model 2470 four-wheel drive tractor was also supplied by Gates to pull the baler. The baler is pto driven and has a peak power requirement of 135 kW. An ammonia application system was fitted to the baler to ammoniate the straw for later feeding tests. Ammonia was directly applied in liquid form at intervals of 17.8 cm across the header. Total width of the header is 1.8 m. Two augers crowd the straw into a 1.2 m width before entry into the baler feed section. Bale dimensions are nominally 1.2 m high by 1.2 m wide with length adjustable to 2.5 m.

Time and motion studies were conducted during October 16 and 17, 1981. The baler was operating in straight, level checks 915 m long and 50 m wide. Baling had been done at irregular intervals prior to this test and approximately 70 bales had already been produced. Fourteen bales were made during the tests of October 16 and 17.

Soil type was silt loam with an average soil cone index of 480 kPa at 15 to 29 cm depth. This is approximately the minimum soil strength required to support the baler (Kamp et al., 1983). The first rainfall in the area

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Article was submitted for publication in September, 1983; reviewed and approved for publication by the Power and Machinery Div. of ASAE in October, 1984. Presented as ASAE No. 82-3588.

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Acknowledgments: The authors wish to express their appreciation to the California Rice Research Board, Pacific Gas and Electric Company, Southern California Gas Company, and California Solid Waste Management Board for support of this research, and to Gates Machinery Company, Willows, CA, Hesston Corp., Hesston, KS, and Vermeer Mfg., Co., Pella, IA, for loan of equipment.

occurred on September 24 and rain appeared at about one week intervals after that.

Rice was a short statured M-9 variety. The stalks had been cut to within 10 cm of the ground by the combine because of severe lodging. The straw spreaders on the combine had been turned off and the straw windrowed behind the combine. The windrows averaged 1.5 m in width. Average straw moisture at the time of baling was 31% wet basis. The inclement weather provided little opportunity for drying the straw below this moisture. Ammoniation of the straw was intended both to improve the nutritional value of the straw and to serve as a preservative when baling at high moisture contents.

Bale Roadsiding

Observations were also made of the bale roadsiding operations. Initially, a forklift was used to move the bales from the field to the temporary storage location at the edge of the field. Because of problems encountered with the bale accumulator on the baler, bales were dropped in the field as they were made. This had the effect of increasing the average roadsiding distance to 500 m per bale. With the continuing rainfall, the forklift was eventually unable to negotiate the soft soil and was replaced with a Massey-Ferguson model 285 two wheel drive tractor with rear mounted forks. Front weights were added to the tractor due to the heavy weights of some of the bales.

Transporation of Bales

Bales were transported a distance of 30 km on flat bed semi-trailers operated by Martin Bros. of Willows, CA. Bales were loaded two at a time with a squeeze type forklift mounted on a high flotation chassis. Time to load and unload two truckloads was measured. Bales were unloaded four at a time with the same squeeze loader at the feedlot where the bales were stored.

Storage of Bales

Bales were stored four high in uncovered stacks. No attempt was made at any time to protect the bales from rain. Observations of the stack were made at intervals throughout the winter.

Comparison with Big Roll Baler

Time and motion studies were also done using a Vermeer 605-F roll baler to substantiate previous studies and to allow direct comparison between the rectangular baler and a roll baler under similar conditions. Observations were also made of the bale roadsiding, transporation, and storage operations. Bales measured 1.5 m wide by 1.8 m in diameter.

PERFORMANCE OF LARGE BALER

Results of the time and motion studies for the large rectangular baler are summarized in Table 1. The baling operation suffered from mechanical difficulties of feeding the heavy windrows, high moisture levels in the straw, and marginal weather and field conditions. Average actual baler capacity measured 3.6 dry t/h.

Major problems were encountered with wrapping of the straw on the cross augers and jamming of the header. Jamming of the feed system usually resulted in failure of the drive shear pin. Adjustment of the twine knotters also proved to be a problem. Some bales were not tied with all six twines and usually broke apart after leaving the bale chamber. Because of the high moisture content, internal pressures in the bale were sometimes sufficient to break the twines 10-15 minutes after bales were dropped even with all six twines tied satisfactorily. Near the levees, the soil would occasionally get too soft to support the tractor and time was lost in moving to another windrow without baling.

TABLE 1. SUMMARY RESULTS OF LARGE RECTANGULAR BALER IN RICE STRAW, OCTOBER 16-17, 1981, BAYLISS, CALIFORNIA

Operation	Equipment used	Observed capacity, dry t/h	Theoretical* capacity, dry t/h
Baling	Large rectangular baler Four-wheel drive tractor.	3.6	13
Roadsiding	Wheel tractor with rear mounted forks	7.3	7.3
Loading	Squeeze loader on self-propelled chassis	22.5	24
Unloading trucks and stacking bales	Squeeze loader	78	84

*Theoretical capacity for the baling operation is observed capacity adjusted by eliminating unscheduled down-time. For loading and unloading, theoretical capacity is observed capacity adjusted by bale density and moisture content.

Eliminating the unscheduled down-time would result in a baler capacity of 13 dry t/h. Down-time could probably be reduced by increasing operator experience with the baler and by turning the windrows with a rake to enhance drying of the straw. The high moisture was felt to be a major problem in feeding the straw, although typical of straw conditions in wet years. The high moisture content also contributed to reduced storage life of the bales.

Weight of each bale produced during the timed trials averaged 1088 kg wet weight or 750 kg dry. Average bale density was 208 kg/m^3 dry basis. At this density, a full truck payload of 24 t could have beed obtained at a moisture content of only 12.6% wet basis.

The bale roadsiding operation went well with little down time except for the loss of some bales which were not tied with all six twines. Average capacity was 10.5 t/h wet weight or 7.3 t/h dry.

Loading and transporation of the bales were accomplished with few problems. Occasionally, the squeeze loader had to be pulled from the mud with a four wheel drive pickup truck. Twenty-eight bales could be placed on each truck consisting of a highway tractor with two trailers. The front trailer was 7.3 m long. The rear was 9.1 m long. Average loading time including tie down was 52 min. Fifteen minutes were required to unload the bales and stack in uncovered storage. The two truckloads observed carried only 19.5 t each because the loads consisted of lower density, lower moisture bales. Actual capacity was 22.5 t/h for loading and 78 t/h for unloading. Adjusting these capacities for the density of the bales obtained during the timed trials implies a theoretical capacity of 24 t/h and 84 t/ha for loading and unloading respectively.

Uncovered storage of the bales allowed almost complete penetration of rain into the stack. After 28 cm of rainfall most of the bales were so badly decomposed that they could not be used in the planned feeding trials at the feedlot. The stack had collapsed by the end of the winter.

Results of the timed trials of the big roll baler were similar to those reported by Dobie et al., (1977). Baler capacity was 5.4 t/h dry weight basis. Roadsiding capacity was essentially the same as with the large rectangular bales. Big roll bales were transported on a flatbed farm trailer and direct comparison with the transporation of large rectangular bales was not made. The use of a 1.2 m wide roll baler greatly improves the transporation economics compared to the 1.5 m wide roll bales observed in this test. With 1.2 m wide bales, a truck payload of 50 to 65% of legal limit can be obtained compared to about 30% of legal limit for 1.5 m wide bales.

The roll bales held up in uncovered storage as long as they were located on a well drained surface and not in contact with another bale. Rotting occurred where bales were in contact with each other and on the bottom of bales that stood in water. Water penetration was limited to the outside surface of the roll bales in a manner similar to that reported by Dobie and Haq (1980).

ECONOMIC ANALYSIS

Economic analyses were made of the large rectangular baling system and alternative straw handling systems. In order to allow direct comparison of different systems, final delivered product form was specified as either (a) cubed straw, or (b) chopped or tubground straw assuming that bales could not be used directly. P.S. Parsons, Agricultural Economist emeritus, University of California, Davis, used capital cost information and assumptions on life to compute total fixed (overhead) and variable (operating) costs per t of straw handled by each piece of equipment. In all cases, the capital cost was for new equipment. Fixed costs include depreciation, interest, taxes, insurance, and shelter. Operating costs include labor, fuel, twine, management, and maintenance. For bales, roadsiding distance was assumed to be 1.6 km with roadsiding capacity of 5.4 t/h. Covered storage was assumed and storage costs were computed to reflect this. A value of 8 t/h was used for the capacity of the large rectangular baler. Costs of tubgrinding straw are based on Arthur et al. (1982).

Figs. 1 and 2 are network charts showing the various alternative systems for delivering straw in the final form. Swathing is assumed to be required in order to harvest the straw at ground level (although Dobie et al. (1982) showed that ground level harvest with the combine was possible) and to allow the straw to dry prior to baling or chopping. The last system shown for cubed straw involves the use of a semi-portable cuber that could be moved to locally central sites to reduce the distance chopped straw needs to be transported. This concept has been developed to a limited extent and needs a great deal more testing.

Transporation costs for each alternative are based on minimum rate tariffs established by the California Public Utilities Commission (PUC) adjusted to reflect actual rates charged. The tariffs have been linearized for direct calculation of transporation costs. For each alternative, a total cost equation was written combining the direct collection and transporation costs. These equations are based on the assumption that transporation is by highway trucks and are linear functions of transporation distance:

$$\text{Total Cost} = c + ax + b$$

c = collection and processing cost, \$/t
a = variable cost of transport, \$/t-km
b = fixed cost of transport including loading and unloading, and truck depreciation, interest, taxes, insurance, and shelter, \$/t
x = one half of the roundtrip transporation distance, km

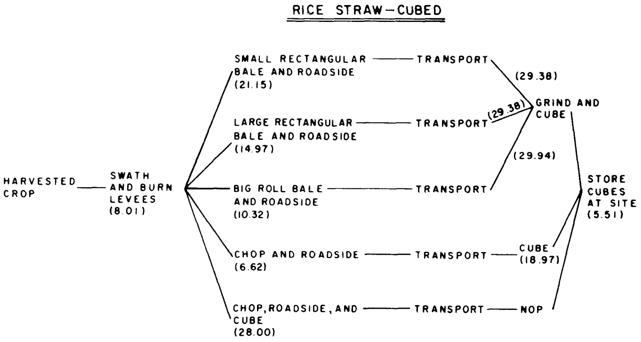

Fig. 1—Network of handling options for cubed rice straw. Numbers in parentheses are 1982 \$/t at zero moisture content. NOP denotes no operation at that stage. Refer to Table 2 for transpiration costs.

Table 2 includes the coefficients of the total cost equations for each of the alternatives. The structure of the PUC transporation tariffs introduces a change of slope in the delivered cost. The distance, d, at which this occurs depends on the package being transported and is included in Table 2. This effect is only seen for long transport distances and would not normally need to be considered. All costs in Table 2 are expressed on a zero moisture (dry) basis.

The delivered cost functions have been plotted against transporation distance in Figs. 3 and 4. The intercept at $x=0$ includes the fixed cost of transporations and should not be construed as the cost to collect the straw without transporting it. For on-farm use of the straw, or short haul distances, the transportation cost can be reduced. Fig. 3 illustrates the potential economic advantage of cubing as close to the field as possible if cubes are the desired end product. For chopped or ground straw, all alternatives except conventional baling start off close to the same cost. The added grinding operation for bales and the extra handling required for standard 3-wire bales makes 3-wire bales more expensive than the big bales or chopping. In both figures, the large rectangular bale system can be seen to have economic advantages when compared to alternative systems currently available.

CONCLUSIONS

1. Large rectangular bale systems offer reduced handling costs for rice straw compared to other currently

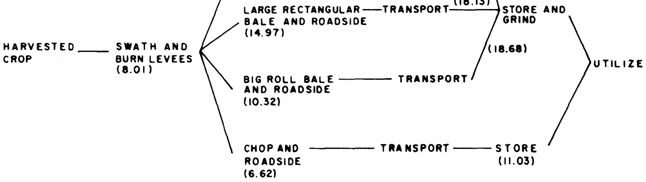

Fig. 2—Network of handling options for chopped or tub ground rice straw. Numbers in parentheses are 1982 \$/t at zero moisture. Refer to Table 2 for transpiration costs.

TABLE 2. DELIVERED COST FUNCTIONS FOR RICE STRAW IN VARIOUS PACKAGES (DELIVERED COST = c + ax + b)

Handling system	Collection and processing cost, c ($/t)	Transporation cost Variable a ($/t-km) x ≤ d	 x > d	 Fixed b ($/t) x ≤ d	 x > d	d* km
Cubes:						
Small rectangular bale	64.05	0.0780	0.0421	8.06	16.00	221
Large rectangular bale	57.87	0.0740	0.0392	7.14	14.51	212
Big roll bale	53.78	0.0937	0.0544	11.37	21.17	249
Chop	39.11	0.1026	0.0629	22.13	32.25	255
Chop and cube	41.52	0.0736	0.0389	7.05	14.37	211
Chopped or Ground:						
Small rectangular bale	47.29	0.0780	0.0421	8.06	16.00	221
Large rectangular bale	41.11	0.0740	0.0392	7.14	14.51	212
Big roll bale	37.01	0.0937	0.0544	11.37	21.17	249
Chop	25.66	0.1026	0.0629	22.13	32.25	255

All costs on dry weight basis.

*The variable d is the distance at which the linearized PUC rate structure introduces a change in slope of transporation cost.

available systems if high baler capacity can be sustained. The potential for reduced transporation costs with large rectangular bales is substantial.

2. Large rectangular bales of straw will require covered storage in areas of high precipitation.

3. Continued development is needed on machines to handle the severe field and straw conditions encountered with rice straw. Current forage harvesting equipment is limited in its ability to handle wet fields and high moisture straw.

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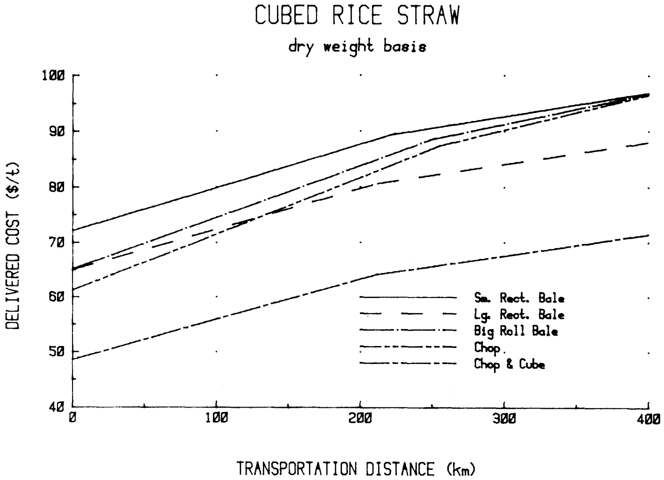

Fig. 3—Delivered cost of cubed rice straw when transported in various packages. Refer to Fig. 1 for network of systems.

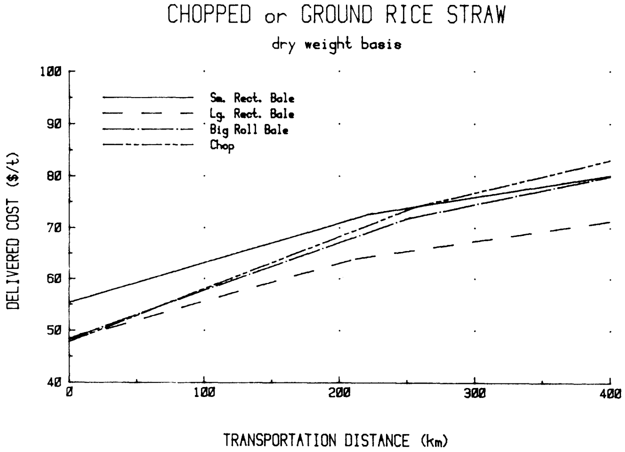

Fig. 4—Delivered cost of chopped or ground rice straw when transported in various packages. Refer to Fig. 2 for network of systems.