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Development of Lifting-Arm Type Round Bale Trailer

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Abstract

A lifting-arm type round bale trailer was designed, built, evaluated for its working rate. The round bale trailer employs 4 lifting arms to load 4 round bales. Each lifting arm consists of 4 round pipes that are arranged to distribute the pressure on the surface of the bales. Two pipes called pickup pipes perform the opening and closing operations. The structure and mechanism enable to load and unload wrapped bales without injuring the film stretched on them. All the operations are easily controlled from the tractor. The operation time required for the transportation of the bales by the trailer was measured, and compared with that of the fount-end loader of a farm tractor. Loading and unloading times required by the trailer were remarkably short, and less than one-fourth of the operation time required by the loader. On the basis of the operation time, the working rate for the transportation of the bales in relation to the traveling distance was estimated. The results showed that the trailer was more efficient than the truck for loading 7 bales within a 1.5 km distance.

Discipline: Agricultural machinery
Additional key words: forage, handling, wrapped bale, silage

Introduction

Forage harvesting system using a round baler and wrapping machine has been disseminated in the past several years in Japan[5]. This system is convenient in terms of labor, working rate, adaptability to changes in the weather conditions, quality of silage and cost of storage[1,4]. There are 2 types of wrapping procedures in these systems: wrapping at the stack lot and wrapping in the field. The latter procedure enables to separate the transportation of bales from the harvesting process because the bales that have been wrapped are removed after the completion of the whole harvesting process. The field wrapping system may save labor and increase the working efficiency.

When the operator handles the wrapped bales, it is important to lift the bales without injuring the film stretched on them. If the film is punctured, air will be introduced into the bale and the silage will be damaged[6]. Many kinds of attachments for wrapped bales are provided for the front-end loader of tractors[3]. This equipment has been used by most of the farmers who have introduced the wrapping system in Japan. The operators puncture the film on bales frequently during handling because the attachments squeeze or grip bales through hydraulic power that can not be controlled accurately.

More than 20 types of round bale trailers for loading and unloading round bales have been developed and they are already available in the market. Several models can be applied to the transportation of the wrapped bales. There are few reports about these trailers[2]. This article reports on the development, construction, and evaluation of the working rate of a new lifting-arm type round bale trailer.

Description of the prototype

1) Design objectives

The objectives of the general design of the round bale trailer are to transport wrapped round bales without injuring the film stretched on them by convenient operation by one person. For safety and convenient operation in narrow or sloping fields, the body should be as short and as low as possible. In addition, it is necessary to hold bales on the trailer

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during the traveling process.

2) General

The lifting-arm type round bale trailer is characterized by the presence of 4 lifting-arms on the frame (Fig. 1). Two arms are located on the right side of the body and 2 others on the left side. One lifting-arm loads 1 round bale. Bales are scooped up from the side of the body, and they are unloaded to both sides of it. The maximum permissible weight of a bale is 800 kg, and the maximum allowable weight capacity of the trailer is 3,200 kg. Bales with a diameter ranging from 120 to 150 cm can be used. The empty weight of the trailer is 1,980 kg, the overall length 430 cm and the overall width 279 cm. When the trailer swings down all the lifting-arms to both sides, the overall width increases from 557 to 607 cm.

The frame of the trailer is of the ladder-type on the main beam, made of steel square pipes. The joint, which is free around the horizontal and vertical axes, is located at the front end of the main beam. The trailer is hitched to the lower-link of the tractor by that joint.

To obtain a low gravitational center, 4 small-sized tires are adapted to the trailer. These tires are on a tandem axle with a leaf spring to follow the terrain and evenly support the rough load or field.

3) Lifting-arm

The lifting-arm (Fig. 2), which consists of a lifting frame (A) and 4 round pipes, swings up and

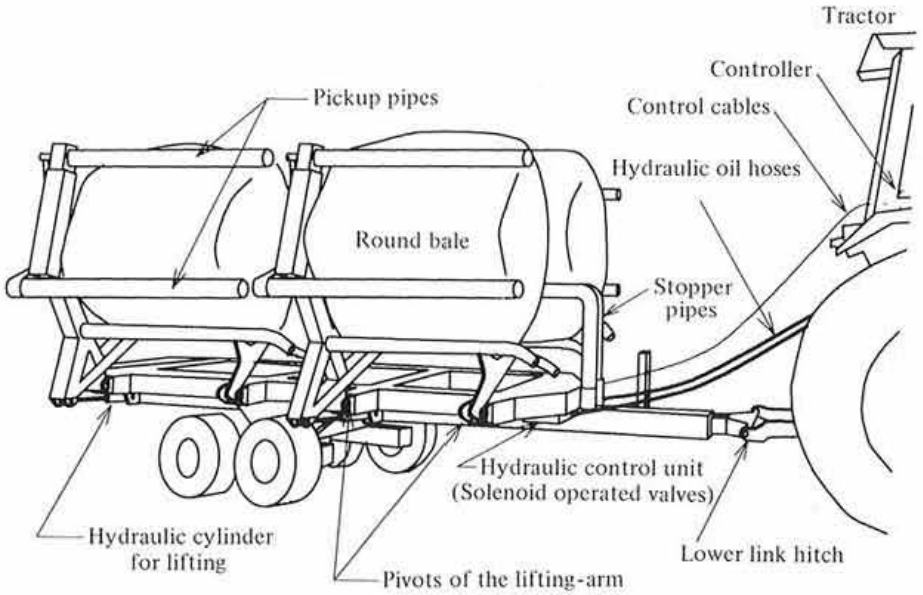

Fig. 1. Schematic lateral view of the trailer

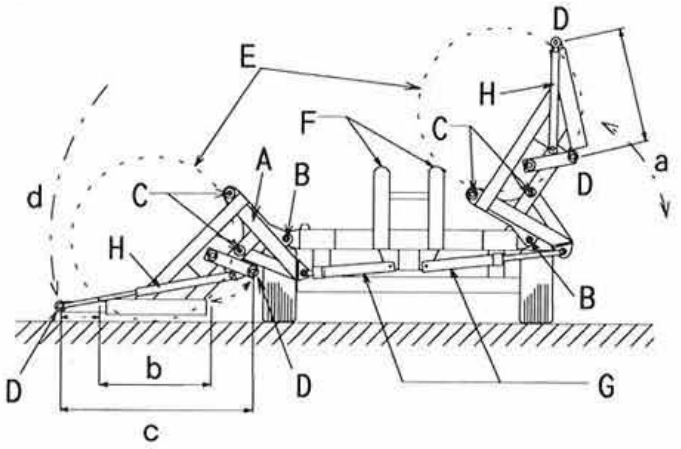

Fig. 2. Schematic rear view of the trailer

down (a) around the pivots (B) on the side of the trailer. The 4 pipes are arranged to distribute the pressure on the surface of the bale while the arm loads it. Inner 2 pipes (C) are fixed to the lifting frame, but outer 2 designated as pickup pipes (D) perform the opening and closing operations. In the closed position (b), the distance between the 2 pipes is 30 cm shorter than the diameter of the bale (E), while in the open position (c), it is 30 cm longer. When the arm loads a bale, the 2 pipes are located in the closed position to lift up a bale from the bottom of the curved surface. For unloading bales, the arms are swung down (d) in the reverse operation, and then the pipes are opened (c) to lift the empty arms without coming into contact with the surface of the bale. This type of lifting-arm can load and unload wrapped round bales without injuring the film stretched on the bales.

Bales of the lifting-arms are held between the pick-up pipes and the stopper pipes (F) that are fixed to the center of the body. This holding mechanism prevents bales from rushing out of the arm during the traveling process.

4) Control system

The trailer has 8 hydraulic cylinders operated by the hydraulic circuit of the tractor. Four of them are used to swing the arms (G), and the 4 others for opening and closing the pickup pipes (H). The movements of these cylinders are independent of one another, and they are controlled by 8 solenoid-operated valves on the trailer. This control system can be easily manipulated from the tractor.

5) Static side-overturning angle

When 2 bales are loaded on the side, the value of the static side-overturning angle to the loaded side should be smallest. The value of the static side-overturning angle is 0.45 rad (26°), even though the weight of 2 bales is 800 kg.

Working rate

In order to estimate the working rate, we determined the operation time required for the transportation of wrapped bales by the trailer and that by a conventional system.

1) Trailer

Operation time required for the tailer to transport 12 round bales was determined. The weight of the bales ranged from 400 to 500 kg and the diameter was 120 cm. These bales were wrapped mechanically and scattered in the field. The maximum output power of the tractor, which drew the trailer, was 58 kW (79 hp). The area of the field was about 1 ha. The traveling distance between the field exit and the stack lot was about 800 m. The operation time observed was separated into: stoppage time to load 4 bales (loading time), traveling time in the field (field traveling time), traveling time on the way to and from the stack lot (transporting time), and stoppage time for unloading 4 bales at the lot (unloading time).

Loading time of the developed trailer was 64 s for 4 bales, which is very short because the trailer can start traveling as soon as the bale is slightly lifted up from the ground. Field traveling time was 225 s for 4 bales. This value depends on the direction of the bales and the distance between the bales. During the present survey, since the average traveling distance in the field was about 430 m, the field traveling speed was estimated to be 6.9 km/h on an average. On the other hand, the traveling speed on the way to and from the stack lot was 16.5 km/h even though 75% of the travel occurred on a rough road. In the lifting-arm type trailer since the course must be turned frequently to introduce the bales into the arm the traveling speed in the field is lower than that on the road. Unloading time was 71 s for 4 bales.

Under these conditions, the total working time for 4 bales was 710 s, and the working rate of the trailer was estimated to be 20.3 bales per h.

2) Conventional systems

In order to estimate the working rate of conventional systems, we calculated the operation time required for handling round bales by the front-end loader of the tractor in 4 cases: loading 2 wrapped bales onto the bed of the dump truck, loading 3 wrapped bales (1 on other 2 bales) onto it, loading 4 wrapped bales onto a flat-bed trailer in a line, and loading 4 hay bales without wrapping onto the trailer. The gripping type round bale handler was mounted with the front-end loader to avoid injuring the film stretched on the bale. The maximum output power of the tractor was 70 kW (95 hp), and the loading capacity of the loader was 950 kg. The bed of the dump truck was 325 cm long × 185 cm wide with sides and rear gate, the height of which is 145 cm from the ground. The bed of the flat-bed trailer was 590 cm long × 220 cm wide. In all the cases, the bales were put within 10 m from the bed

Table 1. Working rates of the front-end loader

Kind of bales	No. of bales	Vehicle	Working rates (min/bale)	
			for loading	for unloading
Wrapped bales	2	Dump truck	1.23	1.34
Wrapped bales	3	Dump truck	1.21	1.24
Wrapped bales	4	Flat-bed trailer	1.52	1.43
Hay bales	4	Flat-bed trailer	0.62	0.81

and loaded and unloaded from the side of the bed.

Working rates for the front-end loader in each case are shown in Table 1. Loading time was nearly equal to the unloading time in each case because the operation was almost identical except for the reversal of the procedure. There was no difference between the load of 2 bales or 3 bales onto the truck. During the handling of the wrapped bales by the loader, the operator should avoid injuring the film stretched on the bale. In addition, since the weight balance of the tractor may be lost due to heavy bales, the operation time required for wrapped bales is longer than that for hay bales.

3) Comparison of working rate

On the basis of the results of motion and time studies, working rates for the distance of the transportation were estimated in 4 cases, 3, 5, 7 bales on a truck for the conventional system (truck system), and 4 bales on the trailer (bale trailer system). Two operators were used in each system. In the truck system, one operator drives the truck and unloads bales at the stack lot using the front-end loader of the tractor, and the other operates a tractor to load bales on the truck in the field. In the bale trailer system, one operator drives the trailer, and the other operates a loader to stack bales at the lot after the trailer unloaded bales. Calculation of the traveling speed and time required for each operation is shown in Table 2. For the truck system, it was assumed that the field traveling time and unloading time would be proportional to the number of bales to load.

The results of the calculation are shown in Fig. 3. Working rate of the trailer was higher than that for 3 bales on a truck within a distance of 4 km, 5 bales within a distance of 2 km, 7 bales within a distance of 1.6 km. The bale trailer system was more efficient than the conventional truck system over a short distance because the loading and unloading times of this system were short. In the conventional truck system, the number of bales on a truck does not enable to increase the working rate over a short distance.

Table 2. Conditions for the estimation of working rates

	Trailer	Dump truck		
No. of bales on a vehicle	4	3	5	7
Field traveling time (s)	225	169	281	394
Loading time (min/bale)	16	75	75	75
Traveling speed on road (km/h)	16.5	30	30	30
Unloading time (min/once)	71	225	375	525

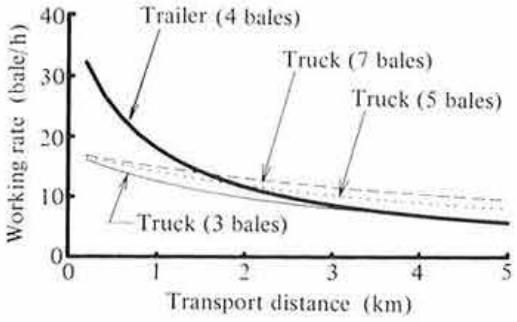

Fig. 3. Working rate of the trailer and the truck with front-end loader

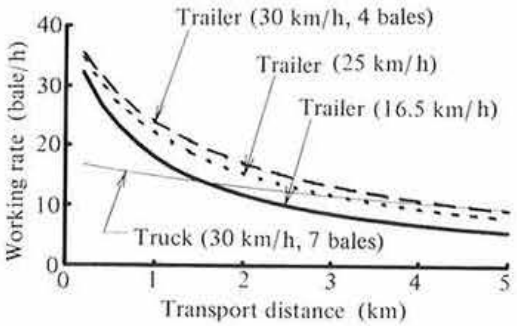

Fig. 4. Effect of traveling speed on working rate of the trailer

Over a long distance, the working rate of the bale trailer system decreased suddenly and was lower than that of the conventional truck system presumably due to the low traveling speed of the tractor. The trailer should be drawn by a farm tractor, with a maximum speed of less than 25 km/h. If 4 lifting-

arms are mounted on a truck, and if the traveling speed is equal to that of the truck, the working rate will be higher than that for 7 bales on a truck within a distance of 5 km (Fig. 4).

Conclusions

(1) The trailer is characterized by the presence of 4 lifting-arms, and transports 4 wrapped bales on each arm. The arms load, unload and hold bales without injuring the film stretched on them.
(2) By using the front-end loader of the tractor, the loading time of the wrapped bales was 73 s per bale, and the unloading time was 77 s per bale. On the other hand, the loading time was 16 s per bale, and unloading time was 71 s per 4 bales when the trailer was used. The lifting-arm system reduced the loading and unloading times.
(3) On the basis of the motion and time studies, working rates for the distance of transportation were estimated. It was shown that the working rate of transportation by the new trailer system was lower than by the truck system over a short distance even though the traveling speed of the tractor was assumed to be 16.5 km/h, which is about half of the speed of the truck. To increase the working rate over a long distance, the traveling speed of the trailer should be increased.
(4) The evaluation of the operations for sudden stoppage, jack-knifing, hill climbing ability, and handling cost is under consideration.

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