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Large Bale Transporter for Small Tractors

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BACKGROUND

The use of large round bales is becoming an increasingly popular method of haymaking in many parts of the United States. A recent survey conducted in the Midwest showed a significant shift in preference from conventional to big roll balers (Long 1975). The large round bales require a completely mechanized handling system, and the potential reduction in labor requirements is a contributing factor in this trend.

Renoll et al. (1975) reported that, when feeding waste was controlled, a round bale system provided less expensive feed than a highly mechanized conventional system. Gill and Van Keuren (1972) listed reduced handling and storage costs as an added advantage of larger hay packages. Lien et al. (1975) concluded that large round bales may become a competitive alternative in areas where commercial transport of hay is required.

Large round bales would appear to offer many important advantages to small-scale operators. First, the reduced labor requirements would be particularly beneficial in that the hiring of laborers not usually associated with the enterprise would be reduced or eliminated. Further, the large bales would provide important flexibility regarding the scheduling of transporting the bales from the field. Conventional bales require immediate transport to avoid significant losses and also require some provisions regarding protection from weathering during storage. Recovery of large round bales, however, can be delayed with no additional risk of loss. This flexibility is particularly desirable when haymaking conflicts with other required operations in the farm enterprise.

The large bales in question are cylindrical packages with diameter and length of up to 1.83 m (6 ft) and up to 680 kg (1500 lb) in weight. Generally, the bales are moved using a tractor equipped with a front-end loader or one of several types of rear-mounted carriers. The simplest of the latter category is mounted directly on the tractor employing auxiliary hydraulics, was designed and constructed. The transporter was designed using standard steel components for all structural members in order to facilitate potential construction in farm shops. The total weight of the transporter (excluding wheels) is approximately 225 kg (296 lb). A sketch of the transporter is shown in Fig. 1.

The foregoing discussion indicates that a simple device which can be used in conjunction with a small utility tractor to transport large round hay bales is needed. The specific objectives of this study were as follows:

1. To design and build a device which can be used in conjunction with a small tractor to safely transport large round hay bales without requiring remote hydraulic cylinders.

2. To conduct experiments to determine the operational characteristics of the device and to evaluate such characteristics vis-a-vis a commercially available carrier which is mounted directly on the lower links of a standard 3-point hitch.

TRANSPORTER DESCRIPTION

A semi-mounted transporter which can be effectively used with small utility tractors (equipped with standard 3-point hitch and hydraulic lift capability) to transport large round hay bales, without requiring auxiliary hydraulics, was designed and constructed. The transporter was designed using standard steel components for all structural members in order to facilitate potential construction in farm shops. The total weight of the transporter (excluding wheels) is approximately 225 kg (296 lb). A sketch of the transporter is shown in Fig. 1.
During loading, two tines (a) are positioned horizontally beneath a bale at ground level. The tines are rigidly joined to perpendicular lever arms (b). The tine assembly is pivoted about short supporting members (c) which extend from the axle (d) of the transporter. Rigid members (e) extending forward from the axle are pinned to a mast assembly (f) which is connected to a category I hitch. A flexible steel cable (g) engages a pulley (i) which is connected to the lever arms extending vertically from the tines. One end of the cable is secured to the mast, while the other end is secured to an assembly (j) which is attached to the tractor drawbar. As the mast is raised by the lower lifting links (k), the tine assembly is rotated toward the tractor, thus lifting and cradling the bale. A flexible steel cable (m) is connected between the mast assembly (f) and the transporter axle (d). As the lower lifting links are raised above a certain point, the entire device is raised, thus suspending the wheels for increased maneuverability when the transporter is not loaded.

A steel chain (l) is used to join the cable pulley to the top of the tine assembly. This chain is used to adjust the distance from the pulley to the tine assembly which, in turn, affects the lifting capacity of the device. After the length of the cable (g) has been set, an increase in the distance between the pulley (i) and the top of the lever arms (b) permits the members (e) extending from the axle to the mast assembly to be more horizontally oriented when lifting begins. The mechanical advantage of the device is increased due to the resulting orientation of support members (c) toward the vertical (Fig. 2). Coincidentally, the lifting capacity of the tractor is also increased as the lifting links (k) are rotated upward. The results of these considerations are described in the following paragraphs.

To estimate the theoretical lifting capability of the transporter, a static analysis was performed on the linkage illustrated in Fig. 2. Tractor linkage dimensions were taken from a 1975 Ford Model 3000 tractor equipped with a category I hitch. An arbitrary lifting range for the lower tractor links was defined such that height above ground level of the lower hitch point (h) varied between 0.254 and 0.762 m (10 and 30 in.). A cylindrical bale, 1.83 m (6 ft) in diameter and 1.83 m (6 ft) long, was assumed to be positioned atop the tines such that contact was made with the perpendicular lever arms. At several positions throughout the lifting range, the equilibrium tangential force at the lower hitch point, \( F \), was determined for each of two assumed bale weights (Fig. 2). The results of this analysis are summarized in Fig. 3.

Curve A-A in Fig. 3 illustrates the tangential force at the lower hitch point (F) required to lift a 680 kg (1500 lb) bale throughout an arbitrary lifting range of 0.254 to 0.762 m (10 to 30 in.). Curve C-C represents the tangential force (F) required for a tractor rated at 26.1 kW (35 hp, drawbar) throughout the same lifting range (ASAE S217.10, § 4.1.1). This curve was computed using linkage dimensions of the previously specified tractor and the requirements set forth in the standard testing procedure for determining hydraulic lift force capacity (ASAE S349). For the assumed linkage specifications, this tractor must be capable of supplying at least the force given by curve C-C at any point throughout the lifting range in order to satisfy the ASAE standard. It is apparent that, for a large bale of this size, the initial lifting force required is greater than the rated lift capacity. However, curve A-A indicates that the required lifting force decreases as the elevation of the lower hitch point (h) increases. Furthermore, at or above \( h = 0.36 \) m (14.2 in.) sufficient tangential force would be available to lift the bale throughout the remainder of the lifting range. It is extremely likely that actual available lifting capacity would exceed that shown in curve C-C, in which the apparent initial deficiency in available lifting force would be smaller or possibly non-existent.

To address the foregoing problem, an analysis was conducted to determine the required tangential force curve corresponding to a minimum h-value of 0.508 m (20 in.). This means that the lower links are horizontal when lifting begins, and this is accomplished by adjusting the distance from the cable pulley to the tine assembly (Fig. 2). The required lifting force for the modified limiting range is represented by curve A'-A'. These results indicate that approximately 120 percent of the required tangential force is available using a 26.1 kW (35 hp) tractor. Further, when the available tangential lifting force is determined for a tractor rated at 18.6 kW (25 hp) (curve D-D), approximately 86

FIG. 2 Illustration of transporter linkage.

FIG. 3 Tangential lifting forces (F) required by experimental transporter compared with available tractor lift capacities.
percent of the initially required tangential lifting force is available. It should be pointed out that while the lifting capacity of the transporter can be increased by modifying the lifting range, such modification results in decreased ground clearance when the bale is in the transport position. The modification described above decreases the final ground clearance by 50 percent, but adequate clearance remains (0.17 m or 6.5 in.) for most circumstances.

Renoll et al. (1975) indicated that typical round bales may weigh considerably less than 680 kg (1500 lb). To examine this possibility, a theoretical determination was made of the tangential force required to lift a 454 kg (1000 lb) bale of identical dimensions using the transporter. Curve B-B is a representation of the required force throughout a lifting range of $0.254 \text{ m} \leq h \leq 0.762 \text{ m}$ (10 to 30 in.). Approximately 80 percent of the required lifting force is available using a 26.1 kW (35 hp) tractor. This indicates that sufficient lifting force would be available with a relatively minor reduction in the lifting range. Curve B'-B' is the required lifting force throughout a lifting range of $0.508 \leq h \leq 0.762 \text{ m}$ (20 to 30 in.) and shows that a tractor rated at 18.6 kW (25 hp) is capable of lifting such a bale while operating at 80 percent of its rated hydraulic capacity.

EXPERIMENTS

Various experiments were conducted to verify the capability of the transporter prototype to safely transport large round hay bales. A cylindrical bale approximately 1.50 m (5 ft) in diameter and 1.50 m (5 ft) in length was used in all of the experiments. The weight of the bale was measured using a ring dynamometer and determined to be 398 kg (877 lb).

To evaluate the tendency of a tractor to tip backward while transporting a large round bale, a series of tests were conducted using a 1975 Ford Model 3000 tractor rated at 28.3 drawbar kW (38 hp). A commercial bale carrier weighing 127 kg (280 lb) was mounted directly on the lower tractor links and used in a comparison of backward-tipping tendency. For each degree of slope, the weight supported by the front wheels (W) of the tractor was determined for the following conditions: (a) tractor with no load, (b) tractor supporting bale with loaded commercial carrier positioned at $h = 0.508 \text{ m}$ (20 in.), and (c) tractor supporting bale with experimental carrier in transport position, $h = 0.762 \text{ m}$ (30 in.). The results of these tests are summarized in Fig. 4.

The results show a sizeable reduction in W resulting from supporting the bale on the rear of the tractor with the commercial transporter as compared to the no load situation. At the maximum slope considered, W was reduced by approximately 50 percent. For heavier bales this tendency would be more pronounced. The remaining data show results corresponding to the experimental transporter. It is interesting to note that, at each slope value, W was greater than the no load situation, thus indicating that supporting the bale using the experimental transporter actually decreases the likelihood of backward-tipping. This is to be expected since the winching cable is anchored to the tractor drawbar. Each data point in Fig. 4 represents the sum of weights measured beneath each of the front tractor tires. In one instance a 15 percent difference in the two weights was noted, however, the maximum difference otherwise noted was 5.8 percent. Such differences could have been caused by not positioning the scales in the same horizontal plane.

The tractor model used in these tests was somewhat larger than is required to lift the above-mentioned bale with the experimental prototype. However, use of the larger tractor (with the maximum recommended front ballast weight of 136 kg [300 lb]) insured that comparative tests involving the commercial rear-mounted carrier could be safety conducted. Although no actual backward tipping occurred, the data suggest that transporting a heavier bale using a smaller tractor and rear-mounted carrier could be hazardous under comparable conditions. Specifically, the front ballast weight represents 35 percent of the value of W in Fig. 4 which corresponds to operating the commercial carrier at 21.3 percent slope. In contrast, the ballast weight is only 17 percent of the value of W recorded for the same slope with no load.

Fig. 5 shows the results of tests conducted using the experimental transporter in conjunction with a 1956 Ford Model 600 tractor rated at 26.1 drawbar kW (35 hp). The asterisk represents the weight supported by the front wheels (W) on a horizontal surface with no load. The symbols represent the observed relationship between W and slope when the test bale was supported (with $h = 0.762 \text{ m}$ [30 in.]) using the transporter prototype. At 17.3 percent slope, W is approximately 87 percent of the value recorded for the 0 percent slope, no load condition. The test bale could not be lifted with this tractor using the rear-mounted carrier, thus no data were
No problem was encountered in lifting the test bale (398 kg [877 lb]) using the smaller tractor and the experimental prototype. When an additional 180 kg (400 lb) was added to the bale using sandbags, a slight adjustment was required to increase the lifting capacity of the device. The small tractor was adequate in all respects with regard to hydraulic lift capacity. Owing to an absence of liquid ballast in the rear tires, some difficulty was encountered in securing adequate traction on the more severe slopes.

The experimental transporter is rigidly connected to the tractor via the 3-point hitch. Trials indicated that sway bars are desirable for maintaining proper alignment of the cable. Such a hitching arrangement dictates a tandem relationship between the transporter axle and rear tractor axle. Tests were conducted on sod surface to quantify the maneuverability of the prototype supporting the test bale in the transport position. Using the large tractor, the mean turning radius (R) achieved was 4.42 m (14.5 ft). The value of R determined using the loaded rear-mounted carrier was 1.26 m (4.1 ft). When the smaller tractor was used the mean value of R was 6.55 m (21.5 ft). Reduced traction owing to the absence of rear wheel liquid ballast contributed to the increased value of R as compared with the larger tractor. While the experimental transporter is characterized by somewhat limited maneuverability, this did not seem to be a serious liability regarding use of the device. Placement of a pivot point between the mast and the prototype axle to improve maneuverability was considered and judged to be unnecessary. The ability to suspend the wheels when the transporter is not loaded significantly enhances maneuverability when the transporter is being positioned for loading. Therefore, the limitations cited are only important when the device is loaded.

SUMMARY AND CONCLUSIONS

A semi-mounted round bale transporter has been designed and constructed. The device can be safely used with small (26.1 kW [35 hp]) in transporting large round hay bales (up to 1.83 m [6 ft] in diameter and 680 kg [1500 lb] in weight). The hydraulic capability associated with a standard 3-point hitch is utilized in lifting the bale, thus requiring no remote hydraulic cylinders. During transport the bale is supported by the transporter wheels thereby eliminating the potential hazard associated with supporting such bales directly upon the 3-point hitch of a small tractor.

A series of experiments was conducted to verify the capability of the transporter. The transporter was successfully tested in conjunction with a small tractor rated at 26.1 kW (35 hp). A round bale (398 kg or 877 lb) was maneuvered over terrain of various degrees of slope with no apparent instability regarding backward-tipping of the tractor. When a commercial carrier mounted directly on the lower links was used, this tractor was unable to lift the test bale. In contrast, the experimental transporter lifted the test bale plus an additional 180 kg (400 lb) with no difficulty.

Additional tests were conducted wherein the prototype was compared to a commercial rear-mounted carrier. A somewhat larger tractor (28.3 kW [38 hp]) was used in connection with both transporter types, and the weight supported by the front tractor wheels was determined on various slopes. Maneuverability of the experimental transporter was determined by measuring turning radius.

The conclusions of the study are as follows:

1. The experimental transporter can be used with a small tractor to lift and transport large bales safely.
2. The experimental transporter was characterized by a significantly smaller backward-tipping tendency than a commercial rear-mounted carrier under similar conditions.
3. While the experimental transporter is characterized by maneuverability limitations, such limitations are serious only with respect to sharp turns at roadway speeds.

The study indicated that the experimental transporter could be used with a tractor as small as 18.6 kW (25 hp) in transporting bales weighing over 454 kg (1000 lb). Thus, it appears that the smallest tractor in most farming operations (equipped with a 3-point hitch and hydraulic lift capability) can be used effectively, without remote hydraulics, in transporting large round bales.

References