Types of bale loaders and their comparative performance

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Abstract. The article provides an overview of different types of technical means for loading bales of silage. Using the program for simulation of the forage harvesting process, computer calculations were made of the comparative efficiency of the operation of loaders of rolls of various types at a rate of haylage harvesting from 100 to 650 tons per shift (10 hours). It has been established that, according to the criterion of unit total costs at a low rate of haylage harvesting - from 100 to 300 tons per shift - loading units with a front loader mounted on a tractor are more efficient. At a higher rate of forage harvesting, it is more efficient to use self-propelled loaders. With an equal unit total cost of funds, self-propelled loaders provide 1.5-2.0 times less labor costs.

1. Introduction

Technology of harvesting haylage in bales wrapped in film has become widespread throughout the world, including Russia, over the past three decades. This is due to the obvious advantages of this technology over other methods of harvesting forage from grasses [1-5]. Due to the uniform wilting of plants, a reduction in the period of field drying of the grass mass to standard moisture content, a high degree of compaction of the mass in rolls, fast and complete sealing of the forage, the loss of nutrients and metabolic energy is reduced by 1.5-2.0 times compared to the traditional harvesting technology haylage in trenches. In comparison with hay harvesting, the loss of the grown crop yield is reduced by 3-4 times [6-10].

The main sub-processes of the "packaged haylage" harvesting technology are:
- mowing with simultaneous crimping of grasses;
- furrowing, tedding and raking the grass into swaths for uniform drying of the grass mass to moisture 50-55 %;
- selection and pressing of grass mass into rolls with high density - more than 350-400 kg/m³;
- loading and transportation of bales of silage to the place of packing and storage;
- wrapping (sealing) a roll with foil;
- stacking of packed rolls in a two-, three-layer stack.

An important place in this technology is given to the link of loading and transportation of haylage, the coordination of its actions with the previous and subsequent technological operations. The total duration of loading and transportation of bales should not exceed the duration of the permissible period from the formation of the bale to its sealing, in order to avoid excessive self-heating of the hay mass and the accompanying loss of feed. In addition to this requirement, loaders must ensure the preservation of the correct shape of the rolls for subsequent high quality wrapping with film.
Therefore, an important task is a reasonable choice of the scheme of transport services for the forage harvesting process, the qualitative and quantitative composition of the link of loading and transport vehicles.

2. Materials and methods

Roll loaders can be roughly divided into 3 main types [11]:
- specialized loaders included in self-loading coil transporters;
- universal loaders mounted on a tractor or car and equipped with a special fork or bale tilter;
- universal self-propelled loaders equipped with a special forks or roll tilters.

The first type includes forklift-manipulators installed on the platform of the coil transporter (Figure 1).

![Figure 1. Self-loading roll transporter TRB-20 with manipulator loader.](image)

Due to the presence of a manipulator and a longitudinal conveyor located on the platform, the self-loading conveyor together with the tractor make up a combined unit that performs the functions of loading, transporting and unloading bales, and does not require additional loading units when servicing the forage harvesting process. However, having a number of advantages, such loader-transporters are not widely used in medium and large agricultural enterprises. Their use is economically feasible only in small enterprises with a roll transport distance of 1-2 km [12]. While in the North Caucasus region, the average distance of transporting rolls from the field to the farm is 5-7 km, and in some organizations it reaches 15-20 km. When the distance from the field to the farm is more than 2 km, self-loading bale transporters are inferior to tractor transport units with universal trailers and automobile transport units. This is due to the low annual load of specialized roll carriers and their low transport speed.

In this regard, in the further part of the work, we are talking only about front-end and self-propelled telescopic loaders mounted on a tractor, which are used to load rolls into road transport and tractor trailers.

Today, the most common technical means for loading rolls in Russia are front-end loaders of domestic production, mounted on a class 1.4 tractor: a universal hopper loader PKU-0.8 (Figure 2a) and a FRONTLIFT-800 loader (Figure 2b).
The PKU-0.8 loader manufactured by Salskselmash LLC (Rostov Region) has a diverse set of working tools: universal gripper, buckets of different sizes, rake grate for working with loose hay and straw materials, pitchfork, log gripper, etc.

![Figure 2](image)

**Figure 2.** Front-end loaders mounted on a tractor class 1.4. Where: a) Universal hopper loader PKU-0.8 with roll tilter; b) Loader FRONTLIFT-800 with bale fork.

Front-end loader FRONTLIFT-800 is manufactured under the license of the Italian company “Tonutti” Krasnokamsk repair and mechanical plant (Perm), which specializes in the production of machines and equipment for harvesting haylage in rolls. The FRONTLIFT-800 universal loader has 16 replaceable working bodies for use in construction, municipal services and agricultural production. A feature of the FRONTLIFT-800 loader design is the presence of the Self Leveling system, which allows you to fix the desired position and angle of rotation of the load when lifting and lowering.

For loading and moving bales of hay and silage not wrapped in film, front loaders are equipped with a universal fork gripper (Figure 2b). To work with rolls packed in film, it is necessary to use roll tilting grippers ZR-1, KNR-2100 or PMT-01 (Figure 2a), which provide not only gripping, moving and lifting the rolls to a height of 3.2–3.4 m, but also turning them by 90° (tilting). This is necessary when stacking rolls for storage. The rotator does not damage the film of the wrapped rolls and can be used when working with unpacked rolls. Most tilters are designed to handle rolls with a diameter of 1.5 to 1.8 m, a length of 1.2–1.5 m and a weight of up to 900 kg. The design of the PRC-2100 rotator includes a replaceable adjusting connecting rod for gripping rolls with a diameter of 0.7 to 1.8 m.

In addition to the front-end loaders listed above, loaders of regional production UNIVERSAL-800, T229, PFU-0.9, PSN-1, PF-1, etc., are used for loading haylage rolls.

In addition to the use of tractor-mounted front loaders, most agricultural producers abroad prefer self-propelled telescopic loaders. Recently, this trend has been observed in agricultural enterprises in Russia. This is due to the significant advantages of self-propelled loaders: a large lifting and lowering height of the load, a higher accuracy of delivering the load to the destination, high maneuverability and cross-country ability.

Self-propelled telescopic lifting equipment combines the advantages of front loaders and cranes. An important advantage of self-propelled telehandlers is their high versatility and dense loading throughout the year. This advantage is due to the availability of a variety of replaceable working bodies, which are quickly replaced when changing the type of cargo being handled.

Set of working bodies can include a bucket, grippers for various types of cargo, crane devices. To work with bales of hay and hay, the loader can be equipped with a fork gripper or a bale gripper - a turner.

Self-propelled telescopic loaders also have two significant drawbacks: a relatively high price and lower fuel economy compared to tractors of the same power. To reduce the cost of the work performed by them, it is necessary to ensure their full load during the year, using both on the field and on the farm, and on construction and household work.
The most widespread in agricultural production in Russia are self-propelled telescopic loaders manufactured by well-known European firms JCB and JLG (England), Claas and Weidemann (Germany), Manitou Group (France), Dieci and Merlo ”, (Italy),“ AUSA ”(Spain). In addition, American-made loaders are used - "Case", "John Deere", "Bobcat", "Caterpillar" and the Belarusian company "Amkodor".

The longest history of the production of self-propelled loaders with a telescopic boom of lifting of cargo has the engineering company "JCB" (England). Today this company has the largest range of loading equipment. It manufactures more than 20 models of loaders, designed for two main areas of activity - construction and agriculture. The Agri series - agricultural special equipment - includes 11 models that provide lifting of loads weighing up to 3.1 tons to a height of up to 9.5 m.

The JCB 531-70 telescopic loader, the most in demand in agriculture, is the most compact of the company's full-size loaders (Figure 3a). Advantages of this model: powerful engine (85 hp); high carrying capacity (up to 3.1 t); good stability; high cross-country ability, thanks to all-wheel drive; high maneuverability, which is ensured by the small width of the chassis and the large steering angle. Maximum lifting height - 7.0 m. Turning radius - 3.7 m. Maximum travel speed - 32 km / h. Loader weight - 6900 kg.

The Scorpion-6030 self-propelled telescopic loader manufactured by Claas has similar technical and operational characteristics (Figure 3b).

![Figure 3. Self-propelled telescopic loaders. Where: a) – JCB 531-70; b) – Scorpion-6030.](image)

The lifting capacity of this loader reaches 3.3 tons. The maximum lifting and lowering height of the load is 6.25 m. Engine power is 90 HP. Loader weight - 6400 kg. With similar characteristics of the analyzed models of self-propelled telescopic loaders produced by Western European and American firms, the Scorpion-6030 loader has a lower price and therefore it was this model that represented the indicated, very representative, group of machines in our calculations.

Another representative of self-propelled telescopic loaders in our study is the Amkodor 527 loader, manufactured in Belarus (Figure 4). The technical characteristics of this model of the loader, in addition to the lifting height (up to 6.8 m), are inferior to Western European counterparts. With a similar engine power (78 hp), its carrying capacity (up to 2.5 tons) is less, and the weight of the machine (8000 kg) is greater than that of similar Western European machines. The maneuverability of the loader is also inferior to analogues - the turning radius is 6.2 m.

The only, but important advantage of this loader is almost half the price on the Russian market compared to analogues from Europe and the USA. For this reason, the Amkodor 527 loader is included in our calculations.
From all the variety of frontal and self-propelled telescopic loaders presented above, in our research we focused on the most common units for working with rolls in Russia. The study presents two frontal loaders PKU-0.8 and FRONTLIFT-800, mounted on a class 1.4 tractor - MTZ-82 and two self-propelled loaders with a telescopic boom for lifting cargo: Amkodor-527 (Belarus) and Scorpion-6030 (Germany). All loaders are equipped with bale grippers (fork or tilter).

To assess the effectiveness of the studied loaders when using them in enterprises of various volumes of haylage harvesting, the rate of haylage harvesting was set in the range from 100 to 650 tons per shift (10 hours). The required rate of forage harvesting was set by the selection of an appropriate set of machines for mowing, wilting and picking up-pressing grasses (the productivity of the machines and their number during the performance of the specified technological operations).

To substantiate rational technological options for the forage harvesting process, units for performing technological operations and the entire complex of harvesting, loading and transport units in relation to specific natural and economic conditions of a region or an individual enterprise, the Stavropol State Agrarian University has developed simulation models of individual sub-processes and the entire forage harvester [13] ... The models consider the forage harvesting process as a complex production system, which includes variable technological properties of the processed material, the impact on the dynamics of forage harvesting of weather factors, the interaction of machines and parts of the complex in accordance with agrotechnical requirements, the reliability of the units [12, 14-17].

To implement the models, a complex of computer programs has been developed. With the use of this complex, machines and assemblies adaptive to production conditions have been substantiated for mowing and raking grasses, for picking-pressing and picking-crushing of grass mass, transportation of haylage.

We also used the developed software package to substantiate rational units for loading haylage bales into vehicles.

3. Research results
Computational experiments performed on a computer with a simulation model of the forage harvesting process made it possible to obtain the results, which are graphically shown in Figure 5. The graphs show the change in the specific total cash costs $S_z$ and the required number of $Na$ aggregates for each studied loader model with an increase in the rate of haylage harvesting for shift (10 hours). It was
found that, according to the criterion of unit total costs, the PKU-0.8 and FRONTLIFT-800 loaders mounted on a class 1.4 tractor at low rates of forage harvesting (up to 300 tons per shift) significantly exceed self-propelled loaders, and at a higher rate are not inferior to them. This is due to the higher cost of the latter. The main advantage of self-propelled loaders - high productivity - cannot be realized at rates of harvesting haylage up to 300 tons per shift. Only at a haylage harvesting rate of about 320-330 tons per shift is the full load achieved during the shift of the Amkodor-527 loader and at a rate of 420-430 tons per shift - the full load of the Scorpion-6030 loader. At these values of the rate of forage harvesting, self-propelled loaders are compared in terms of specific total costs with loaders such as PKU-0.8 and FRONTLIFT-800 mounted on a tractor. The abrupt increase in the unit total costs on the graphs corresponding to various models of loaders (Figure 5) is explained by the addition of additional loading units to the forage harvester complex and, as a result, their insufficient loading and associated downtime. It should be noted that at a haylage harvesting rate of more than 250-270 tons per shift, a larger number of tractor loading units are required, and with an equal unit total cost of money, self-propelled loaders provide lower labor costs.

Figure 5. The efficiency of bale loaders at different rates of haylage harvesting.

Where: 1 – front-end loader KUN-0.8 installed on the MTZ-82 tractor; 2 – front loader FRONTLIFT-800 installed on the MTZ-82 tractor; 3 – self-propelled telescopic loader Amkodor-527; 4 – self-propelled telescopic loader Scorpion-6030.

4. Conclusions
Thus, the analysis of the performance indicators of the loading units shows the advantages of tractor-mounted loaders of the PKU-0.8 and Front Lift types over self-propelled loaders at a rate of haylage harvesting up to 300 tons per shift. At a higher rate of forage harvesting, it is more efficient to use self-propelled loaders: if the unit total cost of funds is equal, self-propelled loaders provide 1.5-2.0 times less labor costs.
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