# Study of the efficiency of the transport support of forage harvesters when harvesting corn for silage in the conditions forest-steppe zone

*Rufan* Galimov[1,2], *Vitaliy* Tikhonovskiy[1], *Yurii* Blynskii[1], *Sergey* Voinash[3*], *Abdul-Mudalif* Dzjasheev[4], *Rail* Khusainov[5], and *Marat* Salimzyanov[6]

[1]Novosibirsk State Agrarian University (NSAU), 160, Dobrolyubova street, Novosibirsk, 630039, Russia
[2]Siberian Federal Scientific Centre for Agrobiotechnologies of the Russian Academy of Sciences, Post office box No. 267, Krasnoobsk settlement, Novosibirsk region, 630501, Russia
[3]Kazan Federal University, 18 Kremlin street, Kazan, Russia
[4]North-Caucasian State Academy, 41Stavropol, Karachay-Cherkess Republic, Cherkessk, 369000, Russia
[5]Kazan State Agrarian University, 65 Karla Marksa str., Kazan, 420015, Russia
[6]Izhevsk State Agricultural Academy, 11 Student str., Izhevsk, 426069, Russia

**Abstract.** In the article, the authors presented methodological approaches and the results of a study of harvesting corn for silage. It has been established that the actual performance of high-performance forage harvesters during harvesting is significantly lower than the ideal one. The main problems were identified - the partial or complete lack of positioning, monitoring and logistics means of vehicles involved in the maintenance of forage harvesters, which leads to downtime and additional costs. Increasing the efficiency of all links of the harvesting and transport process can be achieved by using positioning to lay rational routes for moving machines on the field using the multi-link tractor and road trains. Furthermore, forecasting places and times to replace a vehicle for loading can reduce combined harvester downtime by up to 30% and increase vehicle productivity by 25% due to reduced idle runs across the field.

## 1 Introduction

Prospects for developing animal husbandry in the Novosibirsk region largely depend on providing animals with complete high-quality feed. Today, the cost-effective management of the livestock complex has a direct relationship with the feed cost. Most often, the increase in the cost of the forage base is due to the inclusion of additional costs of the harvesting process: transportation and storage. Large volumes and short agrotechnical deadlines for performing forage harvesting work on farms require the involvement of a large amount of equipment and labour resources; the share of the harvesting and transport process during this period accounts for more than 75% of labour and funds costs [21-25].

* Corresponding author: rufangalimov@yandex.ru

As a result, many agricultural enterprises must harvest chopped green fodder promptly, with a shortage of labour resources and vehicles leading to decreased quality.

Moreover, during harvesting, for the transportation of chopped green mass, many cars from other branches of the agricultural enterprise are often involved, which sometimes need to be more suitable for these purposes. Moreover, the use of vehicles with body extensions for the transportation of green mass leads to an increase in the specific pressure of the wheels on the soil. Therefore, this contradicts the height of drop side body requirements, according to GOST 33987-2016 [1]. The working conditions primarily determine the efficiency of machines for harvesting and transporting green mass.

These conditions in Western Siberia have several specific features, such as unfavourable weather conditions during harvesting crops and a need for more vehicles in enterprises to service high-performance forage harvesters. The study of performance indicators obtained theoretically and experimentally shows that the results and data on the harvesting and transport process differ significantly. So, for example, data obtained theoretically imply uninterrupted transport support of a forage harvester and do not consider downtime, turns, U-turns and unproductive runs of machines across the field.

The study aims to reduce the idle runs of vehicles to improve the system's performance, considering the positioning and monitoring of the harvesting and transport process.

It is necessary to solve the following tasks to achieve this goal:

1. To establish the main statistical patterns characterising harvesting and transporting machines' work harvesting chopped green fodder.
2. To highlight the practical boundaries of transport services for high-performance forage harvesters.
3. Determine the ways of rational construction of the transport process in the transport service by cars and tractor trains.

## 2 Materials and methods

The authors conducted chronometric observations in agricultural enterprises of the Ordynskiy and Kargatskiy districts of the Novosibirsk region to study the patterns of interaction of vehicles with high-performance forage harvesters. At the same time, forage harvesters of different brands and performance and various service vehicles were considered. The object of the study was the process of interaction of vehicles with field choppers. Each year had differences in the number of units of service vehicles, the area of working areas, the yield of maise for silage (hay), and the parameters of high-performance forage harvesters in the field. The harvesting and transport process was considered a system: high-performance forage harvesters serving vehicles, vehicles with increased payload capacity and heavy-duty tractor trains [2].

Chronometric observations of the operation of machines for harvesting silage crops were carried out at agricultural enterprises in the Novosibirsk region. Based on the data obtained, it was revealed that the efficiency indicators of transport service for forage harvesters depend very much on the organisation of the rational composition of the machine and tractor fleet on the field and the control of its work. Therefore, the main task of building a harvesting and transport process is to justify the composition of machines in the system with minimal costs of funds and labour. The most excellent efficiency of its solution is achieved with the help of a multilevel system approach. For this purpose, comprehensive studies were carried out - from substantiating the parameters of harvesting and transport machines and harvesting technologies to transporting them to ensiling sites. When analysing the process, it was considered a system of harvester-service vehicles - ensiling place. The work of harvesters and service vehicles takes place within the field, which can be described by several parameters: configuration, length, width, yield, distance from the site of storage of green

mass, parameters of the forage harvester (reaper width, header type), etc. It is expedient to divide the system into subsystems, to solve the tasks [3]:

- cleaning machines;
- vehicles;
- a place for laying green mass.

The block diagram of the consistent solution of the tasks set should be improved in terms of saving resources and the interconnected functioning of all subsystems of the production process.

The general research methodology included the development of theoretical premises, their experimental verification in laboratory and production conditions, and the economic evaluation of the research results.

As a result of experimental studies, the authors studied the dependence of the harvested area (with which the green mass filled the vehicle (V)) on the volume of the body of the vehicle attendants.

The ideal performance of forage harvesters was determined by a known formula, taking into account: the maximum possible speed according to agrotechnical requirements, the use of 100% coverage, and the limiting shift time utilisation factor.

## 3 Results and discussion

The results of experimental studies revealed significant differences between the ideal and actual performance of forage harvesters (Figure 1). Thus, two high-performance forage harvesters were chosen for timing data: Jaguar 850 with a 4.5-m header and KroneBix 700 with a 7-m-wide title [4].

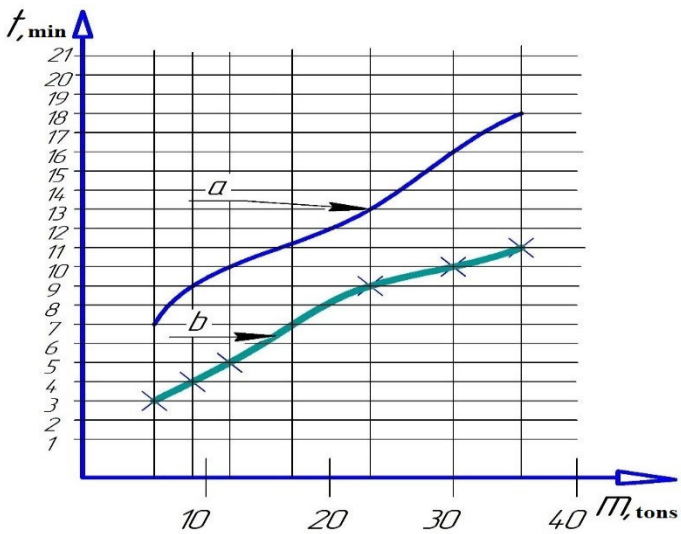


**Fig. 1.** Body filling time depends on the tonnage of the vehicle's body (a – without positioning and monitoring systems; b – with positioning and monitoring systems).

On Figure 1 shows a graphical dependence of the change in the time of filling the body with a green mass on the volume of the vehicle body when harvesting corn for silage and organising transportation without the use of positioning and monitoring systems (Figure 1a) and with positioning and monitoring systems (Figure 1b). Analysis of the curves shows that the change in the filling time of the vehicle body from the use of positioning techniques will

be significant. It depends on the inconsistency in the arrival and departure of vehicles to the forage harvesters in the field since it was found through a passive experiment that the turnover time of the car at transportation distances of more than 10 km takes a significant percentage the time. In other words, using a large number of heavy trailers will not solve the problem of downtime forage harvesters due to unproductive runs on the field. There are delays and idle runs of vehicles across the area, which leads to downtime of forage harvesters and excessive consumption of fuel and lubricants.

For a long period of scientific work, chronometric studies were carried out on forage harvesters of the Jaguar and KroneBix brands (Figure 2).

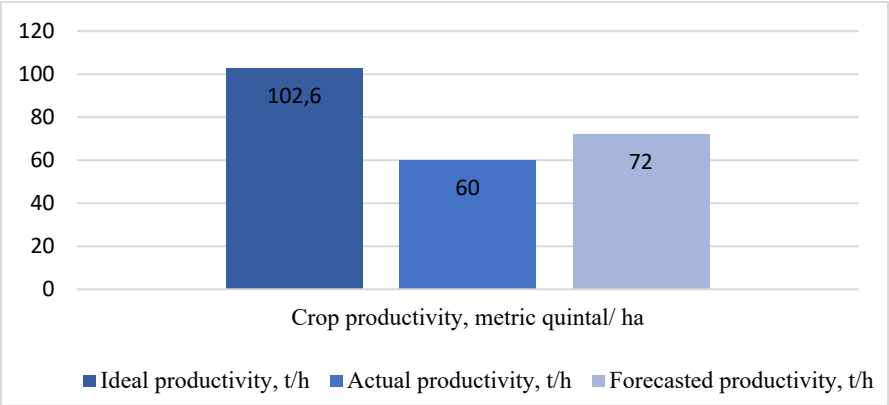


**Fig. 2.** Ideal and actual productivity of forage combine harvester.

The graph's Analysis shows that the performance of high-performance forage harvesters is lower than predicted and well below ideal. Thus, it is necessary to reduce the unproductive runs of vehicles across the field through a more rational design of the schemes for moving cars on the field to increase the performance of the harvesting and transport system as a whole. To this end, the authors used the process of positioning and monitoring the operation of machines of subsystems in the field and at the places of laying green mass.

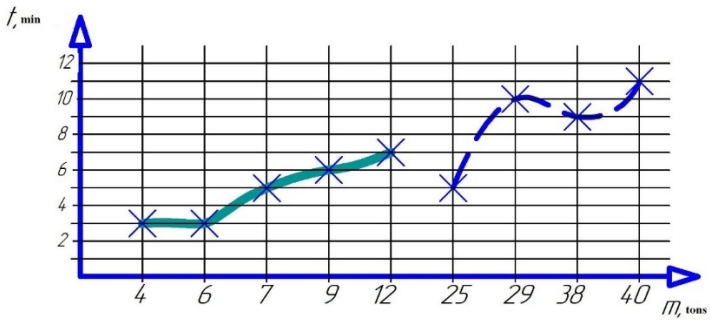


**Fig. 3.** The dependence of the time of filling the body with the green mass on the vehicle's carrying capacity.

The results of the statistical processing of timing data for harvesters are shown in Figure 3. Based on analysing the data obtained, the authors noted that a significant percentage of the time spent by the forage harvester is spent waiting for transport in the field. The data analysis shows that the actual performance is significantly lower than the ideal performance of the Jaguar 860 forage harvester due to the downtime of the combines waiting for vehicles to be loaded. In this case, the logistics of transport service of high-performance forage harvesters

in the harvesting and transport system needs to be improved (Figure 4). The percentage discrepancy between actual and ideal performance is 25%. An increase in the carrying capacity of the vehicle does not increase the efficiency of the harvesting and transport complex. However, it reduces the required number of cars on the field. As seen from the study of the transport service of forage harvesters (Figure 3), it is advisable to choose a rational speed with a known time of filling the body of vehicles for a particular forage harvester. The use of positioning allows you to obtain good routes for servicing cars in the field [5-9].

Thus, during the passive experiment, downtimes of the forage harvester during harvesting and transport operations were recorded by chronometric observations by fixing them on the GPS navigator marks and entering them on an electronic map (Figure 4).

**Fig. 4.** Scheme of the movement of the Jaguar 860 forage harvester, 2020.

It is possible to calculate the area (Figure 5c) that the harvester can harvest in a specific time and predict in advance the place of filling the vehicle body (Figure 5c) based on the experimental data obtained and knowing the technical parameters and ideal performance of the forage harvester, the volume of the vehicle body. With this in mind, the accepted technique allows the development of rational schemes for locating the start and end points of loading vehicle bodies with their minimum idle runs across the field.

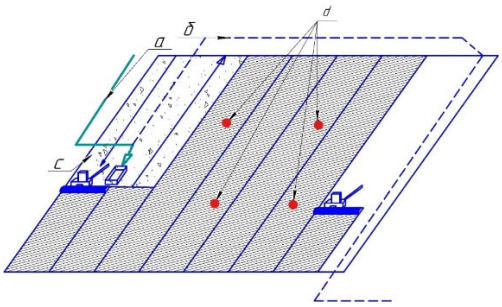


**Fig. 5.** Scheme of the movement of service vehicles on the field (a – with the use of positioning and logistics systems; b – without the use of positioning and logistics systems; c – the area to be harvested depending on the volume of the vehicle body).

Based on this assumption, using positioning and monitoring, the authors calculated the optimal movement routes and the speed of service vehicles both in the field (Figure 5a) and outside it, taking into account the filling time of the body of the car that currently serves the forage harvester.

Forage harvesters with direct loading do not restrict the choice of vehicles for their service [10,11]. The main advantages that determine the widespread introduction of direct transportation are the simplicity of organising work and the ability to use a transport fleet of various carrying capacities and brands [12-20].

The disadvantage of such interaction of the harvesting-transport process is the need for the participation of vehicles directly in the assembly process, which entails significant downtime of up to 13-25% (Figure 3).

The cyclicity of the onset of downtime of forage harvesters can mainly be traced to the change of vehicles. Therefore, we can assume with sufficient probability an increase in the efficiency of the redundant system. However, an increase in the number of trailers, the availability of additional technical support and a change in the internal interconnections of the system elements predetermine the need to assess the economic feasibility of such measures. During the research, the authors found that based on the data obtained when using monitoring and positioning (Figures 2,3,4 and 5), rational schemes for the movement of vehicles on the field were developed, taking into account the specific conditions of agricultural enterprises. Using the proposed recommendations made it possible to reduce the downtime of combine harvesters by up to 30%, and the productivity of vehicles increased by 25% due to a reduction in idle runs across the field. As a result, the productivity of high-performance forage harvesters increased by 20...25%.

## 4 Conclusion

As a result of many years of research, it has been established that the productivity of high-performance forage harvesters when harvesting maise for silage is much lower than the ideal productivity, which is a reserve for its increase. This happens due to downtime of the forage harvester on the field due to the irrational organization of transport services.

Experimental data on the productivity of forage harvesters during the harvesting period with different yields of the harvested material were obtained. The results of experimental studies made it possible to get the main harvesting and transport process patterns depending on the specific production conditions, such as field sizes, head length, harvested material yield, field configuration, and technical parameters of combines and vehicles.

It is possible to predict the place and time when the next service vehicle should arrive at the forage harvester in the field using monitoring and positioning systems and knowing the crop yield and technical characteristics of the forage harvester and service vehicles.

Using the proposed recommendations made it possible to reduce the downtime of combine harvesters by up to 30%, and the productivity of vehicles increased by 25% due to a reduction in idle runs across the field. As a result, the productivity of high-performance forage harvesters increased by 20...25%.

## References

1. On approval of the Rules for the carriage of goods by road (as amended on August 14, 2020) (lost force on January 1, 2021, based on a *Decree of the Government of the Russian Federation* of October 26, 2020, N 1742)
2. R. Galimov, K. Maksimovich, V. Tikhonovskiy, E3S Web of Conferences. EDP Sciences **175**, 05030 (2020)
3. D.V. Grekov, V.R. Petrovets, Bulletin of the Bryansk State Agricultural Academy **4** (2014)
4. R.R. Galimov, K.Yu. Maksimovich, Polzunovskiy almanakh **1**, 69-71 (2020)

5. R.R. Galimov, V.V. Tikhonovskiy, Yu.N. Blynskii, Effective use of agricultural grinders. The role of agricultural science in the sustainable development of rural areas, pp. 564-565 (2018)
6. I.L. Rogovskii, M.V. Hneniuk, S.A. Voinash et al., Journal of Physics: Conference Series, IOP Publishing **679(4)**, 042035 (2020)
7. P. Busato, A. Sopegno, N. Pampuro et al., Biosystems Engineering **180**, 146-160 (2019)
8. C. Amiama, J. Bueno, C. J. Álvarez et al., Computers and Electronics in Agriculture **61(2)**, 192-200 (2008)
9. C.G. Sørensen, D.D. Bochtis, Biosystems Engineering **105(1)**, 41-50 (2010)
10. K.V. Tikhonovskaya, V.V. Tikhonovskiy, Yu. Blynskii, Transportation service of high-performance grain harvesting harvesters. Problems of development technologies of creation, service and use of technical tools in agricultural complex, pp. 22-27 (2017)
11. Yu.N. Blynskii, V.V. Tikhonovskiy, A.V. Sukhosyr, Bulletin of the Novosibirsk State Agrarian University **1**, 52-56 (2009)
12. Yu.N. Blynskii, Siberian Bulletin of Agricultural Science **5**, 76-80 (1989)
13. Yu.N. Blynskii, *Intensification of the harvesting and transport process when using bunkerless machines* (Novosibirsk, 1990)
14. Yu.N. Blynskii, Intensification of fodder crop harvesting with bunkerless harvesters and technique in agricultural **5**, 37-39 (1991)
15. C. Amiama et al., Computers and electronics in agriculture **118**, 56-65 (2015)
16. C. Amiama et al., Biosystems Engineering **134**, 94-104 (2015)
17. D. Pavlou et al., Computers and Electronics in Agriculture **122**, 29-40 (2016)
18. D.S. Paraforos, G.M. Sharipov, H.W. Griepentrog, Computers and Electronics in Agriculture **163**, 104863 (2019)
19. R. Keicher, H. Seufert, Computers and electronics in agriculture **25(1-2)**, 169-194 (2000)
20. D.I. Timshin et al., International Journal of Applied and Fundamental Research **6-2**, 205-210 (2017)
21. V.N. Lunyakin, *Optimization of the harvesting and transport process of harvesting grain crops using a mobile loader:* dis. All-Russian. Research Institute of Village Mechanization. Household (2004)
22. I.L. Rogovskii, B.S. Liubarets, S.A. Voinash et al., Journal of Physics: Conference Series **1679**, 42038 (2020)
23. I.L. Rogovskii, L.L. Titova, S.A. Voinash et al., IOP Conference Series: Earth and Environmental Science **723**, 032032 (2021)
24. N.P. Ayugin, A.V. Morozov, M.V. Ulyanov et al., IOP Conference Series: Earth and Environmental Science **1045**, 012126 (2022)
25. V.V. Nosov, M.G. Tindova, K.A. Zhichkin et al., IOP Conference Series: Earth and Environmental Science **1045**, 012014 (2022)