Feasibility study of the optimal type of a potato harvester for the conditions of the Moscow region

Yu Chutcheva, Zh Telegina and A Dorokhov

1 Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, 49 Timiryazevskaya str., Moscow 127550 Russia

E-mail: yuv.chutcheva@yandex.ru

Abstract. The level of technical equipment of agricultural producers, primarily agricultural machinery, creates the potential aimed at increasing the competitive advantages and efficiency of agricultural production. The consequence of the economic changes that have taken place in the agrarian sector of the Russian economy over the past 30 years has been the physical and moral obsolescence of machinery and equipment, and therefore a significant reduction in the volume of mechanized field work. The observed rates of reproduction of the machine-tractor park neither in terms of quantity nor in terms of energy capacities are sufficient for the full development of the agri-food sector and addressing the issues of food supply of the population. Domestic agricultural producers manage to maintain the technical readiness of the worn-out machine-tractor fleet at the level of 60-62%, which ensures participation in the production of 30-35% of the park of machinery in comparison with the real need. Many years of in-depth study by the authors in the course of scientific research on theoretical approaches to improving the reproduction of the machine-tractor fleet and raising the level of technical equipment for agricultural producers allowed to formulate certain authors’ approaches to solving the existing problems. In particular, as a result of the study, the authors carried out a feasibility study on the use of the optimal type of potato harvester as applied to the conditions of potato cultivation in the Moscow region. That will improve the efficiency of potato cultivation, reduce the losses of producers from injury of tubers in the process of harvesting.

1. Introduction

Overcoming the technical and technological lag is a priority factor in improving the quality and competitiveness of agricultural products. In modern conditions of development, the latest technologies of production, technical re-equipment, staff development are aimed at the rational use of resources, increasing labor productivity, reducing production costs, improving quality and increasing the quantity of products.

The authors are unanimous in the opinion that any technical and technological changes in the production process should have a deep feasibility study.

The works of such scientists as N. I. Vereshchagin, A. N. Skorokhodov, A. G. Levshin, S. B. Pryamov, S. S. Tubalev, and other Russian scientists served as the basis of our research. However, equipment and technologies are in constant development, which indicates the relevance of considering the feasibility of introducing the mechanization tools.
The purpose of this scientific work is to perform a feasibility study on the choice of the optimal type of potato harvester to increase the competitiveness and quality of potato products in the conditions of the Moscow region.

To achieve the goal, the following tasks were set:

1. On the basis of the conducted experimental studies in field conditions, we calculate the feasibility of the optimal type of a potato harvester;
2. We conduct research on the impact of individual factors on the economic performance of potato production.

2. Methods
The reliability of the findings obtained during the study is ensured by applying the following methods:

- Comparisons (when analyzing the characteristics of different types of potato-harvesting equipment);
- Experimental method of research in the field (when comparing the technical and economic characteristics of different types of potato harvesting equipment);
- For determining the effect of individual factors on the indicators of economic efficiency of potato production, we relied on statistical methods (statistical grouping, correlation and regression analysis).

The information and empirical base of the research was based on the results of scientific research conducted by the Federal Scientific Agroengineering Center VIM, as well as the official data coming from periodicals, information and analytical agencies, which reflected various aspects of the analyzed problem.

3. Discussion
Practice shows that in the structure of the cost of agricultural products, the cost of maintaining the machine and tractor fleet is on average up to 35%. The consequence of a reduction in the level of technical equipment, physical and functional obsolescence has been a significant reduction in the volume of mechanized work in the Russian agriculture.

In the general technological chain of production, harvesting potatoes is the most complex and time-consuming process. The results of this technological operation and the timing of its implementation depend on a whole complex of factors. Mechanized harvesting of potatoes on average increases labor productivity by 5 times, helps to reduce crop losses by 25-30%.

The development of science and technology has contributed to the fact that for more than a century, a large variety of designs of potato harvesters has been achieved, aimed at providing high-quality harvesting of potatoes in various climatic conditions. Measures currently being taken to improve harvesting equipment are basically aimed at reducing labor costs and ensuring its comfortable conditions, increasing the efficiency of using agricultural equipment, and increasing the yield of marketable potatoes by reducing injuries, reducing environmental pollution through the use of modern engineering technologies, modern materials.

The relevance of the feasibility study on choosing a certain type of potato harvester was caused by the fact that domestic producers had been buying trailed and self-propelled potato machines with a wide price range abroad in the last years. In this regard, determining the actual efficiency of a particular pita potato harvester under the conditions of large and medium-sized production is of real practical importance.

The performance of the potato harvester is ensured by many factors, including the aggregate composition of soil and moisture in the ridge, the depth of the tubers in the ridge, the design and rowing of the combine, the rows width, the method of harvesting, etc. A significant role belongs to the
process of organizing the cleaning work, especially in large-scale production, when several cleaning units are involved in the cleaning. This requires group organization with the work of each cleaning unit on a separate pen.

Practice shows that in this case, for maximum production per combine, it is necessary to allocate two vehicles, with two or more combines, the best organization is considered a group method. The speed of movement of the harvesting units is determined on the basis of the amount of soil impurities entering the tubers with the tubers. When the amount of impurities is less than 5%, mechanical damage to the tubers or the pulp browning often significantly increase.

In this case, the speed of movement of the potato harvester should be in the range in which the soil layer under the tubers is to be under the end of the first elevator’ web. With a constant percentage of soil impurities in the bunker and increasing the speed of movement of the unit, the mass of potato tubers move along the working bodies of the harvesting machine with a more dense flow, which in turn would reduce the degree of damage to the tubers.

When carrying out harvesting in favorable conditions, i.e. with an admixture of soil in the combine's bunker no more than 5% and in the absence of vegetable impurities, container technology can be used, which involves unloading potato tubers from the bunker into containers located in the back of the vehicle and then transported to the potato storage. This technology ensures minimal mechanical damage to potato tubers during harvesting and transportation.

As part of the study, the criterion for choosing the type of potato-harvesting equipment served as the minimum level of technical damage and injury to potato tubers.

Experimental studies were carried out in the conditions of the Moscow region on the territory of the agricultural land of Ozery CJSC, in which the total area of potato cultivation was about 800 ha. During the tests, the potato variety Gala was used on the basis of a loamy soil type. In the unit with the models of potato harvesters under consideration, the Kamaz 65115 with a loading capacity of 14 tons was used as a motor vehicle.

Field studies demonstrate that a self-propelled two-row bunker combine (with the capacity of 6 tons), despite initial capital investments for its acquisition, provides a greater effect compared to a bunker double-row trailed combine. Its productivity is higher, which is achieved by greater maneuverability, increased separation ability of the working bodies of the combine. Therefore the seasonal production of such a combine, starting from harvesting early potatoes, is over 400 hectares.

On the basis of the results obtained at this stage of the study, it was concluded that their two types of cleaning machines in terms of quality indicators of work have a slight advantage with a self-propelled Dewulf R3060 combine with a bunker. This combine provides for general damages of 13.8% and 3.6% for losses.

With a potato yield of 30 tons / ha and a productivity of 1.1 ha / h, the Dewulf R3060 self-propelled combine harvests 33 tons of potatoes per hour, which is 6 tons or 18.18% more than the AVR-Spirit-6200 combine harvester during the same time.

The results of the study made it possible to conclude that of the two types of harvesters under consideration in terms of infrastructure of large and medium-sized farms, a significant advantage remains for the self-propelled combine Dewulf R3060. Its use in real production conditions requires 3 times less vehicles; therefore, less compacted soil wheels of cars in the process of cleaning, on average, require 15-20% less fuel and lubricants.

Self-propelled combines with a bunker are more expensive, while their replacement capacity is 22% more than combines without a bunker. A wider range of speeds of hydraulic transmissions and their smoother change compared to a tractor allows self-propelled combines to harvest potatoes with less soil admixture than trailed bunker combines.

High performance and annual output of a self-propelled combine with a bunker provides it with greater efficiency in comparison with trailed machines, despite the higher cost. Thus, harvesting potatoes with a self-propelled combine with a Dewulf R3060 bunker provides an additional effect in the amount of 121.21 rubles per ton of harvested potatoes compared with the AVR-Spirit-6200 combine.
Figure 1. Justification of the optimal choice of potato harvester.

The advantages of the Dewulf R3060 self-propelled bunker combine were more pronounced in the adverse conditions of the 2017 harvest season. High soil moisture due to rains during the harvesting period led to the stalling of tractors and vehicles working in the fields with trailed combines with a bunker. The self-propelled combine with reduced performance showed the best results in the conditions of harvesting with high soil moisture.
Table 1. Comparative economic characteristics of the use of potato harvesters.

| Type of combine | Cleaned, ha | Productivity, t / ha | Gross yield, t | The price of cars, mln. rub. | Total costs, rub / ha | Costs, rub / t |
|-----------------|-------------|----------------------|---------------|-----------------------------|----------------------|----------------|
| Self-propelled combines | | | | | | |
| The Dewulf R3060 combine with a bunker | 470.0 | 30.0 | 15050.0 | 22.56 | 48000.0 | 1600.0 |
| Trailed combines | | | | | | |
| The combine AVR-Spirit-6200 + tractor John Deer 6920 | 330.0 | -/- | 10150.0 | 17.04* | 51636.36 | 1721.2 |

* Taking into account the cost of the tractor part.

Table 2. The quality of work of potato harvesters on loamy soils of the Moscow region.

| Indicators | The Dewulf R3060 combine with a bunker | The combine with a bunker AVR-Spirit-6200 + tractor John Deer 6920 |
|------------|----------------------------------------|---------------------------------------------------------------|
| Soil moisture,% | 30.7 | 30 |
| Productivity, t / ha | 30 | 6.2 |
| Row width, cm | 75 | |
| Sort | Gala | |
| Hardness at the depth of the layer, MPa | 0.56 | |
| Clean tubers in containers,% | 96.2 | 93.5 |
| Impurity of soil,% | 4.1 | 6.2 |
| Impurity of plant residues,% | 0.0 | 0.5 |
| Total damage to 100 tubers,% including external: | 13.4 | 16.2 |
| – Peeled skin over ½ surface | 5.8 | 7.2 |
| – Rips and cracks in the pulp | 3.0 | 3.8 |
| – Sliced | 0.0 | 0.3 |
| Internal: | | |
| Darkening pulp from blows | 4.6 | 4.9 |
| Losses for the combine,% | 3.5 | 3.9 |

A self-propelled combine provides a faster filling of the bunker than that of a trailed one, which occurs due to lower turnaround time and higher average speed due to higher maneuverability and perfect adjustment of the working bodies. These factors provide an increased soil separation, which is described in more detail in Table 2.

Most (about 35%) is the duration in the range of 11-20 minutes when working in fields with a yield of 30 tons / ha. The minimum interval assumes that in the bunker during the next unloading, a part of the potato remained because of the vehicle being fully loaded. The maximum interval, which also occurred during the study, suggests that the combine operates on short rutting with several turns or that the combine stops to clean the working members or to eliminate other minor interferences. In the course of the experiment, the harvesters worked in fields with a rut length from 600 to 800 meters.
In a trailed harvester, the filling time of the bunker is somewhat longer; it is about 16–25 minutes due to the lower working speed of movement and a large amount of time for turns. Compared with the self-propelled trailers, the trailed combine is almost 30% cheaper. However, its operation requires a powerful tractor, the cost of which is partially transferred to the cost price of potatoes.

The smaller the potato heap of tubers with the mechanical damage (external and internal), the higher the technical and economic effect of the technological operations of harvesting and post-harvest processing of potatoes. Tubers with mechanical damage during storage lose their weight and are also more susceptible to disease. The total loss during the storage of tubers with mechanical damage is 5-7% higher than that of intact ones.

The greatest likelihood of damage to potato tubers (6.2-8.2%) occurs during the process of harvesting, separating, and transporting tubers at the elevator of a potato harvester; the source of injury is the shaker. No less high probability of damage to tubers (5.1-13.4%) occurs on the drop from the loading conveyor to the bunker storage of a potato harvester without the option of automatic control of the height of fall. This is due to the excess of the initial height of the fall, which is 0.9 m against the permissible height of 0.3 m.

During the storage, the loss of potatoes after harvesting with a self-propelled combine with a bunker was lower compared to the losses after harvesting with a trailed combine. In particular, their value was 9.7 and 11.9%, respectively. Such a difference was caused by the magnitude of the natural mass loss, because potato tubers had a higher percentage of damage to the pulp.

To determine the impact of individual factors on the indicators of economic efficiency of potato production, the method of statistical grouping and correlation and regression analysis were used.

The main factors that affect the financial result from potato production (profit per 1 ha, thousand rubles) were as follows: yield, c/ha; labor costs for 1 centner, man-hours; the level of marketability, %; the share of fertilizer in the total costs, %.

To determine the influence of these factors on the efficiency of potato production, the interdependence between the main indicators was revealed using the method of statistical groupings. For this purpose, statistical information was processed for 30 agricultural organizations of the Moscow region.

As a criterion of production efficiency, the profit per 1 hectare of planting, thousand rubles was taken (Y).

The factors influencing the result are selected:

- $X_1$ – Yield, c / ha;
- $X_2$ – Labor costs for 1 centner, man-h;
- $X_3$ – Level of marketability, %;
- $X_4$ – The share of fertilizer in the total cost, %.

As a result of calculations, the following correlation model was obtained:

$$Y = -2531.3 + 7.89X_1 - 11.72 X_2 + 4.61 X_3 + 10.47X_4$$

The above correlation model with a high degree of confidence characterizes the formation of profit per 1 ha of crops, depending on the size of the selected factors. The coefficient of multiple regression $R = 0.873$ indicates the presence of a strong relationship between the selected factors and the effective indicator. And since the coefficient of determination is equal to 0.792, this means that the effective indicator $Y$ by 79.2% is formed due to the selected factors. With the help of the obtained correlation model, a number of conclusions can be made about ways to increase profits. Thus, due to the increase in yield per unit, the profit will increase by 7.89 thousand rubles on 1 hectare of crops. The increase in labor costs per 1 centner of products will lead to a decrease in profits per 1 ha by 11.72 thousand rubles. An increase in the level of marketability leads to an increase in profits (the profit will increase by 4.61 thousand rubles with each increase of the corresponding factor per unit). The increase in the share of the cost of fertilizer in the total cost of potato production will lead to an increase in profit per 1 hectare by 10.47 thousand rubles per unit increase factor.
As a result of the study, the reduced costs and the annual economic effect from the use of the Dewulf R3060 self-propelled potato harvester as a result of reduced operating costs were determined. It is clearly presented in Table 3.

Table 3. Calculation of the annual economic effect from the use of the Dewulf R3060 self-propelled potato harvester in comparison with the considered AVR-Spirit-6200 potato harvester models.

| Cost items                              | Designation | Units   | Dewulf R3060 self-propelled potato harvester |
|-----------------------------------------|-------------|---------|---------------------------------------------|
| Annual economic effect due to lower     | $\mathcal{E}_y$ | rub / ha | 873.52                                      |
| operating costs                         |             |         | 410554.4                                    |
| The economic effect of reducing the loss in tubers | $\mathcal{E}_n$ | rub / ha | 1142.60                                     |
|                                         |             |         | 537022                                      |
| The economic effect (loss) from reducing (increasing) damage to tubers | $\mathcal{E}_{\text{non}}$ | rub / ha | 829.31                                      |
|                                         |             |         | 389775.7                                    |
| Total annual economic effect            | $\mathcal{E}_{\text{sum}}$ | rub / ha | 6945.43                                     |
|                                         |             |         | 1337352.1                                   |

In addition to the annual savings resulting from the improvement of technical and economic indicators of machine operation, the economic effect was obtained from reducing losses and damage to tubers when harvesting potatoes.

The economic effect of reducing the loss of tubers during the operation of the self-propelled potato harvester Dewulf R3060 is calculated using the following formula:

$$\mathcal{E}_y = B_y \cdot Y_k \cdot a_n \cdot \Pi_y,$$

(1)

where $Y_k$ – average potato yield, t / ha; $a_n$ – loss reduction ratio; $\Pi_y$ – price of food potato, rub / t

$$\mathcal{E}_{\text{non}} = B_y \cdot Y_k \cdot a_{\text{non}} \cdot \Pi_y,$$

(2)

where $a_{\text{non}}$ – tuber damage reduction ratio; $\Pi_y$– food price difference and damaged tubers, rub.

Thus, on the basis of research results, the use of the Dewulf R3060 self-propelled potato harvester with a bunker for transporting potatoes from the field by cars equipped with a conical bunker with a movable bottom is recommended as the best option for harvesting potatoes for large and medium-sized production with growing in loamy soil. It is also recommended for laying potatoes for storage using a direct-flow technology with a receiving bunker equipped with a shallow soil separator and small tubers, with unloading vehicles at the storage facility into the receiving bunker according to a two-channel scheme.

4. Suggestions for future research
The prospect of further research includes a feasibility study on the use of innovative means of harvesting potato tubers or improved existing analogues in order to minimize losses incurred by potato producers from injuring tubers during harvesting.

5. Conclusion
The constant and dynamic development of technology and technology demonstrates the need for a feasibility study of machinery and equipment being introduced into production.

Since one of the main problems during harvesting in potato production is injury to tubers, the consequence of which is the deterioration of agricultural products, reducing its marketability; therefore, a valid approach to the choice of potato harvesting equipment is relevant.
The study was carried out in the conditions of the Moscow region in the territory of the Ozery CJSC, specializing in potato growing. The research clearly demonstrates that among their two types of harvesting machines (in terms of quality performance indicators) the advantage has the self-propelled combine Dewulf R3060 with a bunker. The advantages of the Dewulf R3060 self-propelled bunker combine were more apparent in the conditions of harvesting with high soil moisture.

In the course of calculating the optimal type of a potato harvester, a number of factors that affect the financial result from potato production (profit per 1 hectare, thousand rubles) were considered: yield, c/ha; labor costs for 1 centner, man-hours; the level of marketability, %; the share of fertilizer in the total costs, %.

Based on the research results, the use of the Dewulf R3060 self-propelled potato harvester with a bunker is recommended as the best option for harvesting potatoes for large and medium-sized production with cultivation in loamy soil, providing an annual economic effect (as a result of reducing operating costs) of 873.52 rub/ha. Moreover, the economic effect from reducing losses of tubers is 1142.60 rub/ha, and the economic effect from reducing damage to tubers is 829.31 rub/ha.

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