

# Mechanised Potato Harvesting: Technical Aspects and Economic Implications for Potato Production

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## ABSTRACT

Mechanised potato harvesting is a critical operation in modern potato production systems, as it directly affects labour requirements, harvesting efficiency, and overall farm profitability. The aim of this study was to evaluate the technical performance and economic implications of mechanised potato harvesting under field conditions in western Serbia. Field experiments were conducted over three consecutive seasons (2021-2023) on a 2-ha potato plot using a tractor-mounted two-row potato harvester. The effects of year, gear ratio, and row length on harvesting time were analysed as critical operational factors.

Harvesting time varied considerably depending on operational conditions, ranging from 19.0 to 23.6 s for short rows (10 m) and from 275 to 321 s for long rows (150 m). A three-factor analysis of variance (ANOVA) revealed that year, gear ratio, and row length all had a highly significant influence on harvesting time ( $p < 0.001$ ), with row length identified as the dominant factor affecting operational efficiency. A higher gear ratio consistently reduced harvesting time, indicating the importance of appropriate machine settings.

In addition to technical performance, an economic evaluation of potato production was carried out. Total production costs increased from 1,167,420 RSD in 2021 to 1,667,740 RSD in 2023, mainly due to higher prices for seed potatoes, fertilisers, fuel, and plant protection products. Over the same period, revenues rose from 2,520,000 RSD to 3,600,000 RSD, resulting in a substantial improvement in gross margin of approximately 43%, reaching 1,932,260 RSD (about 16,518 EUR) in 2023.

The findings demonstrate that mechanised potato harvesting, when properly optimised through appropriate field design and machine operation parameters, ensures high technical efficiency and maintains stable profitability even under rising input costs. Integrating technical and economic evaluations is therefore essential for the sustainable management of mechanised potato production systems.

**Keywords:** potato, mechanization, harvesting, economic analysis, profitability.

## INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world, with annual production exceeding 370 million tons (FAO, 2022). Its wide adaptability, high nutritional value, and role in both fresh consumption and processing industries make it essential for global food security. In Serbia, potato is cultivated on approximately 25,000 ha, primarily in mountainous and hilly regions, but yields remain modest at 20-35 t/ha, lower than the EU average of 35-45 t/ha.

Harvesting is one of the most labor-intensive operations in potato production. Manual harvesting is slow, labor-demanding,

and often associated with higher tuber losses. Mechanized harvesting significantly reduces labor requirements, improves timeliness, and allows for higher field capacity and lower post-harvest losses (Kowalski et al., 2021). However, its efficiency depends on both machine parameters and operational factors such as speed, soil conditions, and row design.

Recent studies in Romanian Agricultural Research underline the importance of combining technical and economic perspectives. Tican et al. (2025) demonstrated that innovative culture systems for mini-tubers improve production efficiency, while Hermeziu and Negrușeri (2024) reported that disease outbreaks such as *Alternaria* can significantly affect yields, emphasizing the need for integrated crop and

mechanization management. Similarly, Marin et al. (2023) highlighted the evolution of mechanization in Romanian agriculture, showing that adoption levels strongly influence productivity and farm viability.

The objectives of this study were:

- To analyze the influence of year, gear ratio, and row length on harvesting time using a two-row potato harvester.
- To assess the economic profitability of potato production through detailed cost and revenue analysis for three years (2021-2023).

## MATERIAL AND METHODS

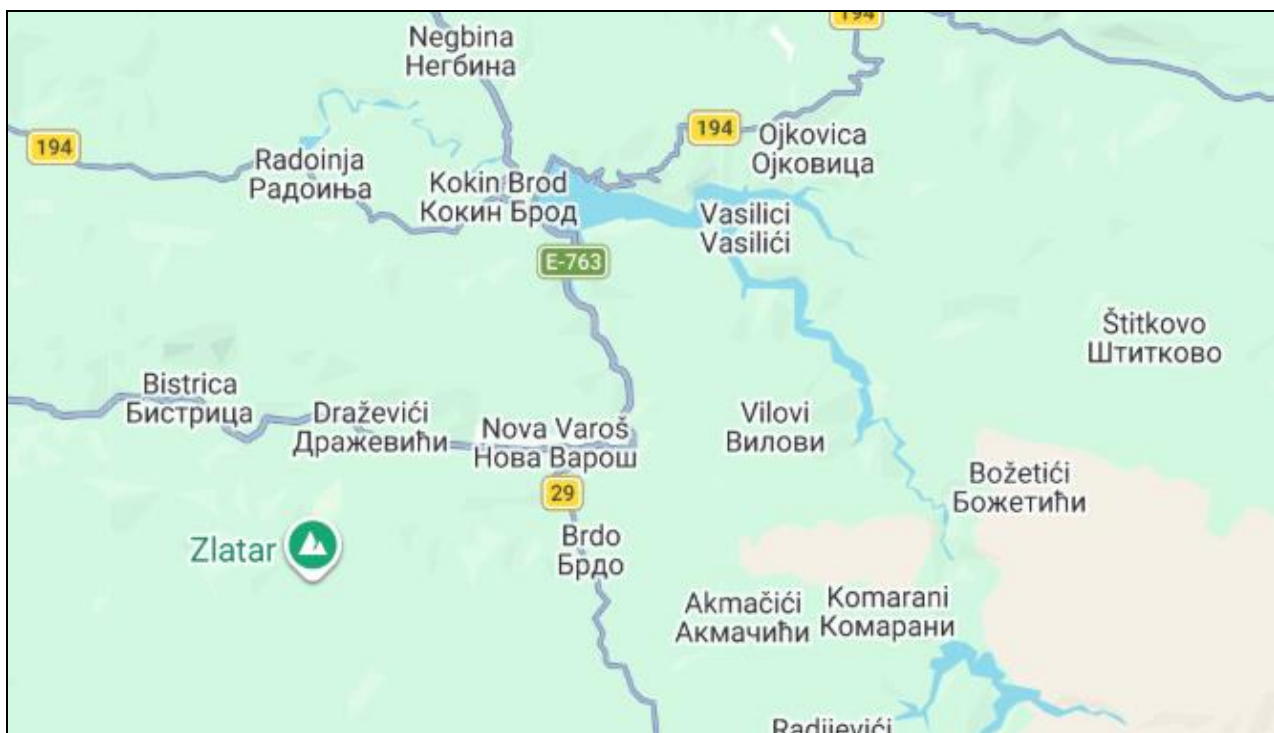
### *Site description*

The potato plantation was located in the village of Vilovi near Nova Varoš, at coordinates 43°27'29" N, 19°51'54" E. Vilovi is situated in the southwestern part of the Republic of Serbia. Nearby towns include

Nova Varoš, Sjenica, Ivanjica, and Arilje (Figure 1). The altitude is 1,150 m. Potatoes of the Agria variety were planted over three years (2021, 2022, 2023) on an area of 2 ha. The soil was classified as loamy with moderate fertility. Standard crop management practices were applied: conventional tillage, certified seed potatoes, fertilisation with NPK and urea, irrigation, and crop protection with registered pesticides.

### *Machinery description*

Harvesting in 2023 was carried out between 15<sup>th</sup> of September and 15<sup>th</sup> of October using a Rolmet two-row potato harvester (U609/0-2) (Figure 2), mounted on a tractor and driven by the PTO. The machine lifts the tubers, separates them from the soil, and deposits them in a swath behind the implement.



Source: Google Maps.

Figure 1. Location of experiment



Figure 2. Rolmet two-row potato harvester (U609/0-2)

The digger can be used on light and medium soils, very rocky plantations, and grassy soils. It can operate on flat ground as well as on slopes with an angle not exceeding 5 degrees (8%). It is designed as a tractor

attachment with three attachment points and is driven by a cardan shaft.

Table 1 presents the main technical characteristics of the digger.

Table 1. Technical characteristics of the Rolmet two-row potato harvester (U609/0-2)

Parameter	Value
Number of rows	2
Working width (m)	1.25–1.35
Row spacing (cm)	62.5–67.5
Digging depth (cm)	25.0
Field capacity (ha/h)	0.30–0.40
Operating speed (km/h)	up to 15.0
Length (m)	5.54
Width (m)	1.59
Height (m)	1.20
Mass (kg)	730

#### Experimental design

A factorial design was used with:  
 Year (2021, 2022, 2023);  
 Gear ratio (IV and V);  
 Row length (10 m and 150 m);  
 Dependent variable: harvesting time (s).  
 Each treatment had three replications.

#### Economic analysis

Annual costs were categorised as seed potatoes, fertilisers, pesticides, fuel, and labour. Revenues were calculated from sales of table and seed potatoes at market prices.

Gross margin (contribution margin) is an intermediate result for each production line, capturing profit as well as fixed costs which are not separately recorded. It serves as a quick and reliable indicator for comparing production lines and selecting the most economically viable option (Tomić et al., 2013). It is calculated as  $CM = GP - VC$ , where  $GP = (q \times p) + s$ , and should be adjusted to the relevant unit of calculation (per ha/are in crop production, per head in livestock production). The farm's overall profit is assessed only by considering the

results of all production lines (Jeločnik et al., 2010; Subić et al., 2015).

#### *Statistical analysis*

Data were analyzed using a three-factor ANOVA (Year  $\times$  Gear  $\times$  Row length). Significance level:  $p < 0.05$ .

## RESULTS AND DISCUSSION

#### *Technical performance*

The analysis of harvesting times (Table 2) showed that all three main factors significantly

influenced machine performance (Table 3). Short rows consistently required more time per harvested unit due to frequent turning, while longer rows allowed for higher efficiency. Gear ratio V outperformed gear ratio IV in all years. Year-to-year differences were moderate, with slightly improved performance in 2023 compared to 2021, possibly due to better soil conditions and operator experience.

Row length was the dominant factor, followed by gear ratio and year.

Table 2. Mean harvesting time (s) by year, gear ratio, and row length

Year	Gear	Row length (m)	Mean time (s)
2021	IV	10	23.5
		150	320
	V	10	19.8
		150	285
2022	IV	10	22.9
		150	310
	V	10	19.5
		150	280
2023	IV	10	22.3
		150	300
	V	10	19.1
		150	275

Table 3. Three-factor ANOVA for harvesting time (s)

Source of variation	df	F-value	p-value
Year	2	11.2	<0.001 ***
Gear ratio	1	49.7	<0.001 ***
Row length	1	5480	<0.001 ***
Year $\times$ Gear	2	3.6	<0.05 *
Year $\times$ Row length	2	5.1	<0.01 **
Gear $\times$ Row length	1	22.4	<0.001 ***
Year $\times$ Gear $\times$ Row length	2	1.2	ns
Error	24	–	–

Legend: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns - not significant.

#### *Economic analysis*

The economic evaluation showed that seed potatoes consistently accounted for the

largest share of variable costs (approximately 65%), followed by fertilizers, pesticides, fuel, and labor (Table 4).

Table 4. Cost structure by category (2021-2023, 2 ha)

Cost category	2021 (RSD)	2022 (RSD)	2023 (RSD)
Seed potatoes	756,000	918,000	1,080,000
Fertilizers	109,200	135,000	156,000
Pesticides	110,600	136,000	158,000
Fuel	104,120	126,000	148,740
Labor	87,500	105,000	125,000
Total variable costs	1,167,420	1,420,000	1,667,740

Revenues rose significantly over the three years, primarily due to higher potato prices, while costs also increased, driven by seed,

fuel, and fertilizer prices. Gross margin increased by approximately 43% between 2021 and 2023 (Table 5).

Table 5. Revenues and Gross Margin

Year	Revenues (RSD)	Gross margin (RSD)	Gross margin (EUR)
2021	2,520,000	1,352,580	11,560
2022	2,880,000	1,460,000	12,500
2023	3,600,000	1,932,260	16,518

### *Technical Performance and Operational Efficiency*

The results indicate that row length is the most critical factor affecting the efficiency of mechanized harvesting. Short rows (10 m) significantly increase the proportion of non-productive time due to frequent turning and maneuvering, confirming that field design is essential for maximizing machine throughput. Row length was the dominant factor affecting efficiency, supporting earlier findings that longer rows reduce non-productive time associated with turning and aligning.

Additionally, the use of gear ratio V consistently reduced harvesting time compared to gear IV across all seasons. This demonstrates that higher forward speeds - up to 15 km/h according to the technical specifications of the Rolmet harvester - directly improve field capacity. This is consistent with the findings of Hoque et al. (2024), who demonstrated that higher forward speeds increase efficiency without significant yield losses, provided that machine adjustments are appropriate. However, the operator must maintain an optimal balance to prevent tuber damage.

### *Temporal Variability and the "Learning Effect"*

The moderate improvement in performance observed in 2023 compared to 2021 suggests a combination of factors:

**Environmental conditions:** variations in soil moisture and structure between years can affect how easily the harvester lifts tubers and separates soil.

**Operator experience:** The reduction in harvesting time likely reflects a learning

curve, as the operator becomes more skilled at matching the machine to field conditions and synchronizing operations over time.

### *Economic resilience amidst cost inflation*

The economic analysis shows that potato production in Serbia remains highly profitable despite significant increases in input costs. Although total production costs rose by about 43% from 2021 to 2023, revenues increased even more rapidly, resulting in a substantial 43% improvement in gross margin.

Seed potatoes are the largest financial burden, accounting for around 65% of total costs. This is consistent with reports from Eastern Europe.

**Input trends:** While fuel and fertilizer prices followed global inflationary trends (World Bank, 2022), these were effectively offset by stronger market prices for the Agria variety.

**Regional patterns:** Similar profitability trends were observed in Romania, where increased input costs were offset by higher revenues.

### *Sustainability and the role of mechanization*

Given the current labor shortages in rural Serbia, mechanization is now essential for sustainability rather than optional. In addition to replacing costly or unavailable manual labor, the use of a two-row harvester ensures timely operations. This is crucial, as delayed harvesting can lead to quality deterioration and increased vulnerability to disease. However, excessive harvesting speed should be avoided, as it may increase tuber damage.

Future studies should integrate mechanization with precision agriculture tools, such as yield monitoring, sensors, and drones, to optimize operations and better predict profitability under fluctuating market and climate conditions. Furthermore, modern analytical approaches combined with precision agriculture may contribute to more sustainable crop management. Analysis of mineral composition has been identified as a promising tool for monitoring and distinguishing different crop production systems, while the use of sensors, drones, and advanced monitoring systems enables more precise and efficient agricultural management (Cvijanović et al., 2021; Gavrilović et al., 2024).

## CONCLUSIONS

This study provides a comprehensive analysis of the technical efficiency and economic performance of fully mechanized potato harvesting under field conditions of western Serbia over a three-year period. Based on the findings, the following conclusions can be drawn:

**Field design and operational efficiency:** Row length was identified as the most critical factor influencing harvesting efficiency. Longer rows minimize non-productive time, such as turning and maneuvering, thereby directly maximizing machine throughput. Planning plots with extended row lengths remains the primary recommendation for producers aiming to reduce costs per unit area.

**Technical optimization:** Proper selection of gear ratio and forward speed is essential for reducing harvesting time. The study confirms that with adequate machine calibration, high field capacity can be achieved without compromising tuber quality, and operator experience is crucial for consistently achieving these optimal results.

**Economic resilience:** Despite a significant increase in input costs - particularly seed potatoes, which account for 65% of expenses - production demonstrated remarkable economic resilience. The rise in market prices for potatoes effectively offset inflationary pressures,

resulting in an increase in gross margin of over 40% during the three-year period.

**Regional relevance and small-scale adaptation:** The findings of this study have broader implications beyond the local context, providing a scalable model for small and medium-sized farms across the Balkan region. The results show that even on smaller plots typical of Southeast European agriculture, strategic mechanization can effectively offset high input costs and labor shortages.

**Necessity of mechanization:** With increasing rural labor shortages, fully mechanized harvesting is now essential for the survival and competitiveness of farms. It addresses the labor deficit and ensures timely harvesting, which is critical for preserving tuber quality and preventing disease.

**Future directions:** To advance further, it is recommended to integrate precision agriculture tools, such as yield monitoring sensors and digital plot mapping. These technologies can enable accurate resource management and further optimize profitability under fluctuating market and climate conditions.

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